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DMITRI KESSEL / THE LIFE PICTURE COLLECTION / GETTY IMAGES; (DETAIL) ROY W. MCDIARMID

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Photo by Jeff Pidgeon / Drawings by Iris Gottlieb

THIS PAGE: Keir Dullea in *2001: A Space Odyssey* (1968)



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BY SUE HALPERN AND BILL MCKIBBEN

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Contributors



ILLUSTRATIONS BY **Sam Hoh**

Mandy Barker

The award-winning British photographer has been collecting objects on beaches since she was a child, but now, instead of seashells and driftwood, Barker collects plastic—everything from toothbrushes to Transformers ("Plastic Planet," p. 68). "I wanted my photos to connect with the people of Hong Kong," where she visited 19 beaches over three years. "These are objects that are part of everyday life. So when the people see where it ends up, hopefully, it will help them think about recycling and reusing—and not buying as much plastic." Barker's work has been exhibited in China, Belgium and England.

Sloane Crosley

The author of the best-selling essay collections *I Was Told There'd Be Cake* and *How Did You Get This Number* was struck, she says, "by the untold philosophical history of nylons" (p. 16). "We owe nylons a debt of gratitude, however out of fashion they may be for certain age groups. They made way for tights as we know them—and if you spend your winters in the Northeast, you know how important tights are." Crosley's first novel, *The Clasp*, will be out in October.

Chris Colin

The San Francisco-based journalist was happy to revisit *Back to the Future Part II*, the sci-fi comedy set in the far-off future year of 2015, for his story about the inventors of the real-life hoverboard (p. 52). "This is a team attempting to defy the most fundamental law of the planet," Colin says. "I think it's good for the species to swing for the fences like this. Not because I foresee a significant chunk of humanity getting to the grocery store on hoverboards anytime soon—but because inventions like the Hendo keep things exciting and remind us that we should never stop trying to shoot the moon." Colin has written for the *New Yorker*, *Outside* and *Wired*. His latest book, co-authored with Rob Baedeker, is a guide to conversing, *What to Talk About*.



Charles Floyd

For the illustrator and former art director at *National Geographic*, the topic of bioengineered organs hits close to home. Four years ago, Floyd underwent open heart surgery for an aortic valve replacement. Now he looks forward to a future where bioengineered organs might be a reality. Floyd hopes his illustrations (p. 40) "help readers understand where in the body the organs currently being researched for replacement are located."

Elizabeth Royte

The Brooklyn-based science journalist published *Garbage Land*, a 2005 book about what happens to our trash after it leaves the curb. "I haven't been able to stop thinking about where things come from and where they go," Royte says. Still, she was shocked by a recent study estimating that 8.8 million tons of plastic flows into the ocean annually (p. 68). Royte is also the author of *Bottlemania: Big Business, Local Springs, and the Battle Over America's Drinking Water.*

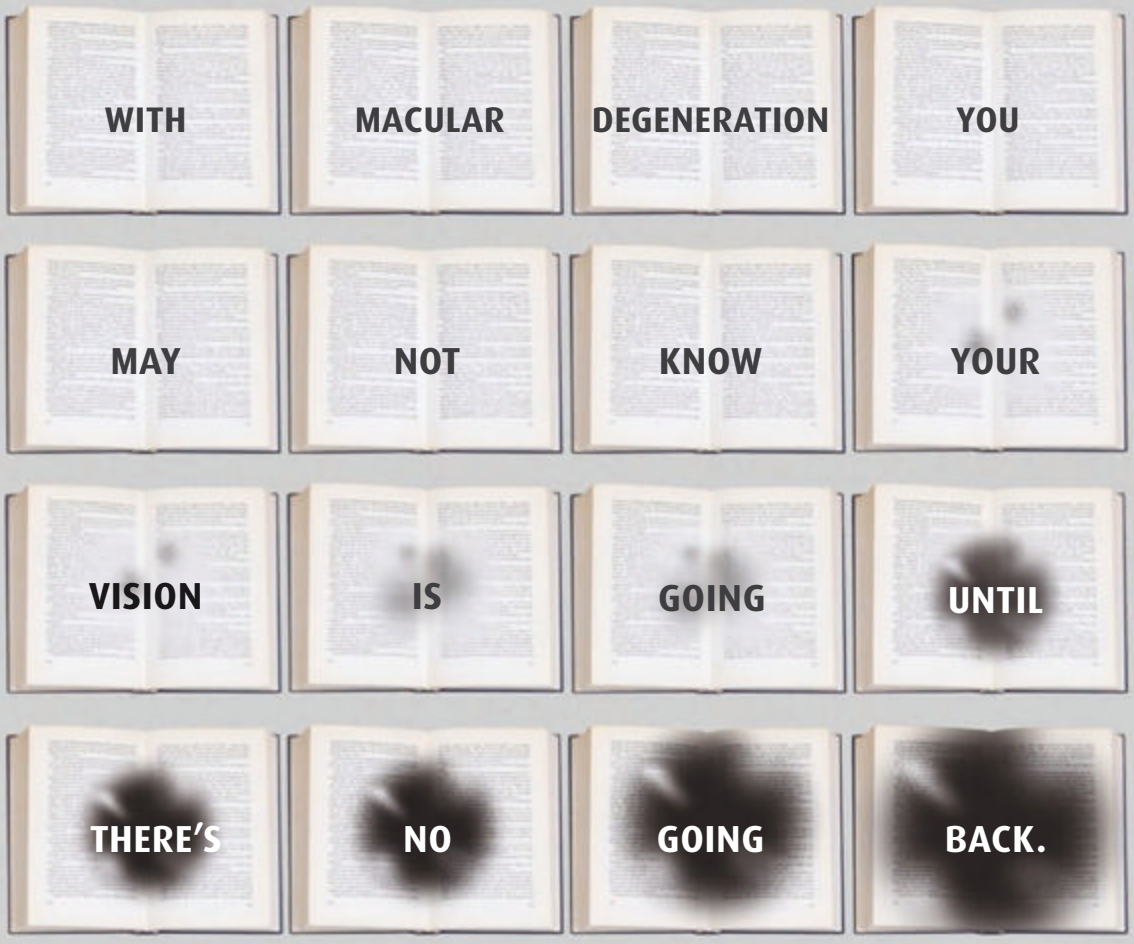
Kendrick Brinson and David Walter Banks

The photographers, who are married and live in Los Angeles, traveled to a biodynamic farm to shoot "Farmer D" for "Welcome to Farmtopia" (p. 74). "There's something about farming next to a beach that is so rare and beautiful," Banks says. "Farmer D was such an inspiration," Brinson adds, "that after we came home, we started our own compost." Their work has been featured in *Rolling Stone*, the *New Yorker* and *Sports Illustrated*.

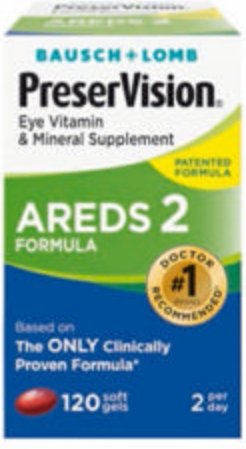


Bruce Sterling

The renowned American science fiction writer has always seen Arthur C. Clarke as the iconic futurist (p. 66). "The passage of a million years was nothing to Clarke—he was happy with the remote past and remote future and had profound insights that other people didn't have." Sterling, author of more than 17 books, won the Arthur C. Clarke Award for the best science fiction novel published in the U.K. for *Distraction*. Two of his novelettes also won Hugo Awards.



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Discussion

Nice piece about Via Margutta made famous in #RomanHoliday #rome #travel via @SmithsonianMag

@lizwarkentin ON TWITTER

FROM THE EDITORS *Our story about Rome's Via Margutta, and the list of other endearing small streets around the world, triggered an epidemic of wanderlust. "I really want to visit here one day," Geni Wojtek says on Facebook. "I fell in love with it in* Roman Holiday *and I would love to see it in person." Many people nominated their own favorite small streets, such as Ulica Mariacka in Gdansk, Poland, Sogukcesme Sokagi in Istanbul, Carnaby Street in London and Kurfürstendamm in Berlin. The stunning glacier photography by Daniel Beltrá garnered thousands of likes on Facebook and hundreds of retweets. As @ZoeRey says, "Awesome, awesome #Climate Change images." Another reader, Richard Bonomo, was pleased all around. "This has to be the best issue I've ever read, between the Civil War and Lafayette articles. I was fascinated with the unknown details in those articles."*



Chauvet Cave

I only wish that technology was more often used for projects of importance to the human species as a whole, like this one. This is an amazing re-creation that will in turn save the original site for generations to come.

Tricia Rowan Brensinger
FACEBOOK

Lovely article, but how typical that the men would want to dismiss the female discoverer of the cave!

Mia Tolliver
FACEBOOK

It is a great idea since the actual cave is too fragile to allow anyone but select scientists inside. Sure, we can see the reprints and photos, but to be able to experience the actual scale of the cave was what was always missing.

Chris Hsu
FACEBOOK

Bee Comeback

How about asking if our yards were returned to meadows ["Field Study"]? There is a good chance your yard was once a pasture or a field. Even if hedgerows were re-established, as they once were after the Dust Bowl, and ditches did not get mowed, a huge impact would be made.

Theresa Rosado
FACEBOOK

Solar Plane

Excellent news here ["The Light Stuff"]. We hope the solar-cells technology will be refined and nano-reduced for commercial use as a source of basic energy for everything.

Hernan Saavedra
FACEBOOK

This is a great adventure with, I'm sure, some benefits for mankind in the future. Bulldozers were an offshoot of WWI tanks, and web strapping, necessary to cargo shipping, was a Vietnam-era enlightenment. I guess the trees cut down to widen a landing strip at one stop is a small price to pay for this adventure if it pans out.

howieone
ONLINE COMMENT

Lincoln Lessons

I have read many books and articles relating to Abraham Lincoln's assassination, but none more personal and intense than "The Blood Relics" in your March issue. James L. Swanson's engrossing story makes you feel you are right there at the time it happened. I was spellbound. And the photos by Cade Martin gave insight and added to the drama. As Mr. Swanson suggests, it is sad that until now we have dismissed the Ford Theatre historical site on the April 14 anniversary; but, hopefully, this article and changes being made will inspire future generations to remember that history is more than just numbers and dates—it is part of our everyday lives.

Kitty Pherson
MACUNGIE, PENNSYLVANIA

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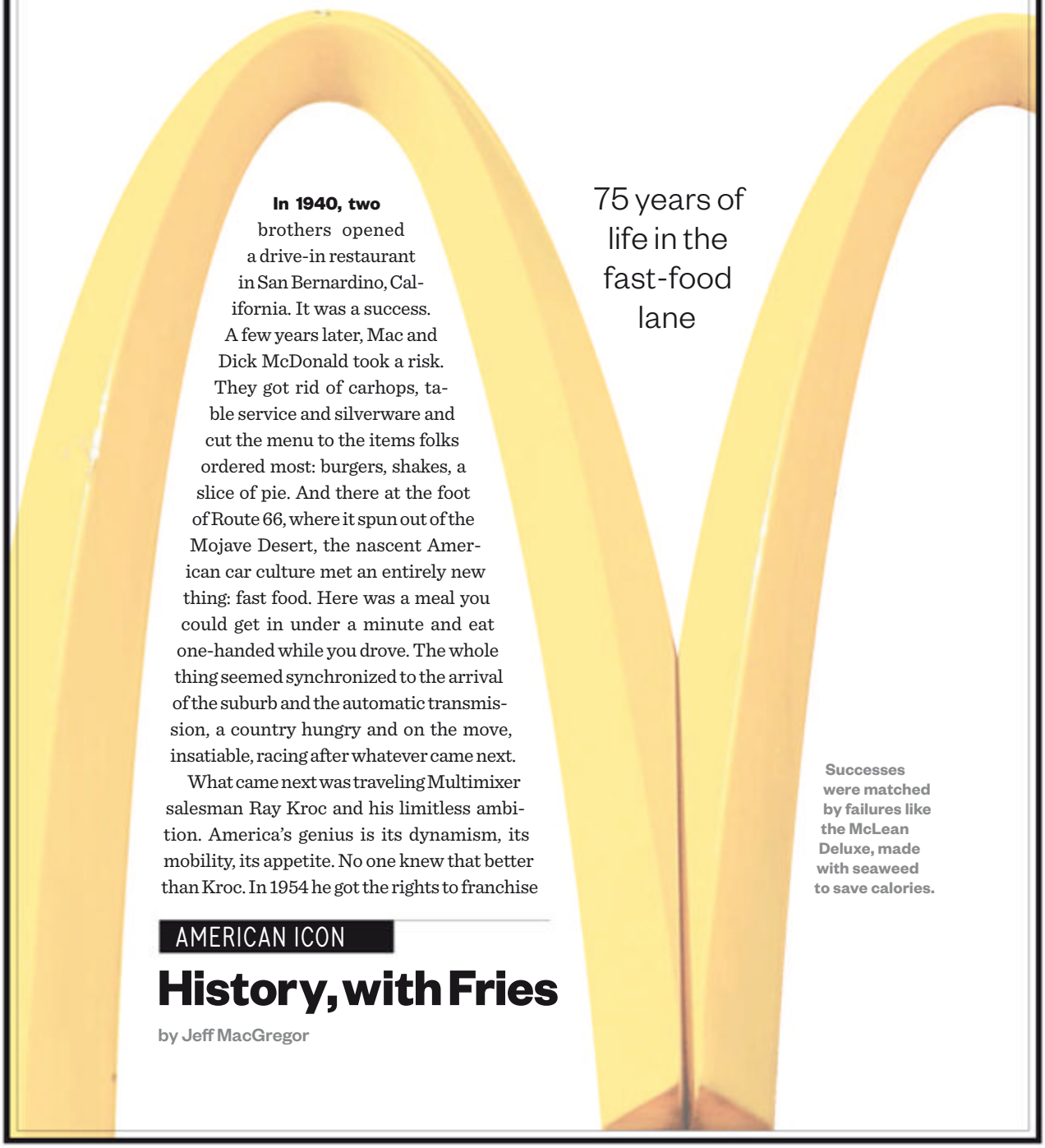




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Phenomena

A CURATED LOOK AT SCIENCE, HISTORY & CULTURE



75 years of life in the fast-food lane

In 1940, two brothers opened a drive-in restaurant in San Bernardino, California. It was a success. A few years later, Mac and Dick McDonald took a risk. They got rid of carhops, table service and silverware and cut the menu to the items folks ordered most: burgers, shakes, a slice of pie. And there at the foot of Route 66, where it spun out of the Mojave Desert, the nascent American car culture met an entirely new thing: fast food. Here was a meal you could get in under a minute and eat one-handed while you drove. The whole thing seemed synchronized to the arrival of the suburb and the automatic transmission, a country hungry and on the move, insatiable, racing after whatever came next.

What came next was traveling Multimixer salesman Ray Kroc and his limitless ambition. America's genius is its dynamism, its mobility, its appetite. No one knew that better than Kroc. In 1954 he got the rights to franchise

Successes were matched by failures like the McLean Deluxe, made with seaweed to save calories.

AMERICAN ICON

History, with Fries

by Jeff MacGregor

KEVIN BRITLAND / ALAMY

McDonald's from coast to coast, and soon oversaw the founding of Hamburger University to teach not culinary passion, nor even cooking: Hamburgerology was about standardization, the perfection of repetition, speedy systems management. Every uniform would be spotless, every cheeseburger the same from Bangor to La Jolla.

For every success there was a corresponding failure. For every Filet-O-Fish—launched in 1962 to capture Lenten business—there was a Hula Burger, because who doesn't love grilled pineapple on a bun?

McDonald's wasn't the first chain or the first drive-in or even the first drive-*thru* (that was Red's Giant Hamburg in Springfield, Missouri, 1947-1984). But it was the only one with Kroc's franchise model, and the first to perfect its mass advertising. If slogans like "The Closest Thing to Home" were good, even better was "Twoallbeefpattiesspecialsaucelettucecheesepicklesonionsonasesameseedbun." And *Ad Age* called "You Deserve a Break Today" the best commercial jingle of the 20th century.

By the late 1990s McDonald's claimed to be opening a new store somewhere every three hours. In Sweden, that meant a ski-thru. In Sedona, Arizona, turquoise arches.

Today nearly two million people work at 36,000 McDonald's stores in 119 countries. But there's a price to dynamism and supersized growth. Over the years McDonald's has been called out for everything from devastated rainforests to childhood obesity, from gassy cattle to empty calories and cultural imperialism. In March, new CEO Steve Easterbrook, a Brit, was handed the keys to the corner office the week before it was announced that sales were swooning worldwide. The company issued a statement referring to its "urgent need to evolve." Within a month, it had announced plans to diversify its offerings—a Big Mac fashion line, a trial run for all-day breakfast.

But can McDonald's really change? Licking its wounds from dollar-menu wars with Wendy's and Burger King, feeling pressure from "fast casuals" like Chipotle, undermined by regional insurgents like In-N-Out Burger and Shake Shack, McDonald's is beset, Goliath on a battlefield thick with Davids.

And yet 75 years later the fries are still unrivaled, the service mostly efficient and mostly polite. Drive through and the whole car smells like your first day at the state fair. The cheeseburger—centerpiece of a global empire—is as it ever was, a precision system for the delivery of discrete condiment flavors. Onion. Mustard. Pickle. Ketchup. The last bite always bun, slightly bittersweet, tasting of sugar and raw white flour. Maybe the McNuggets you ordered were forgotten, your empty hand grasping those few loose fries at the bottom of the bag. But you've gone too far too fast to go back now.

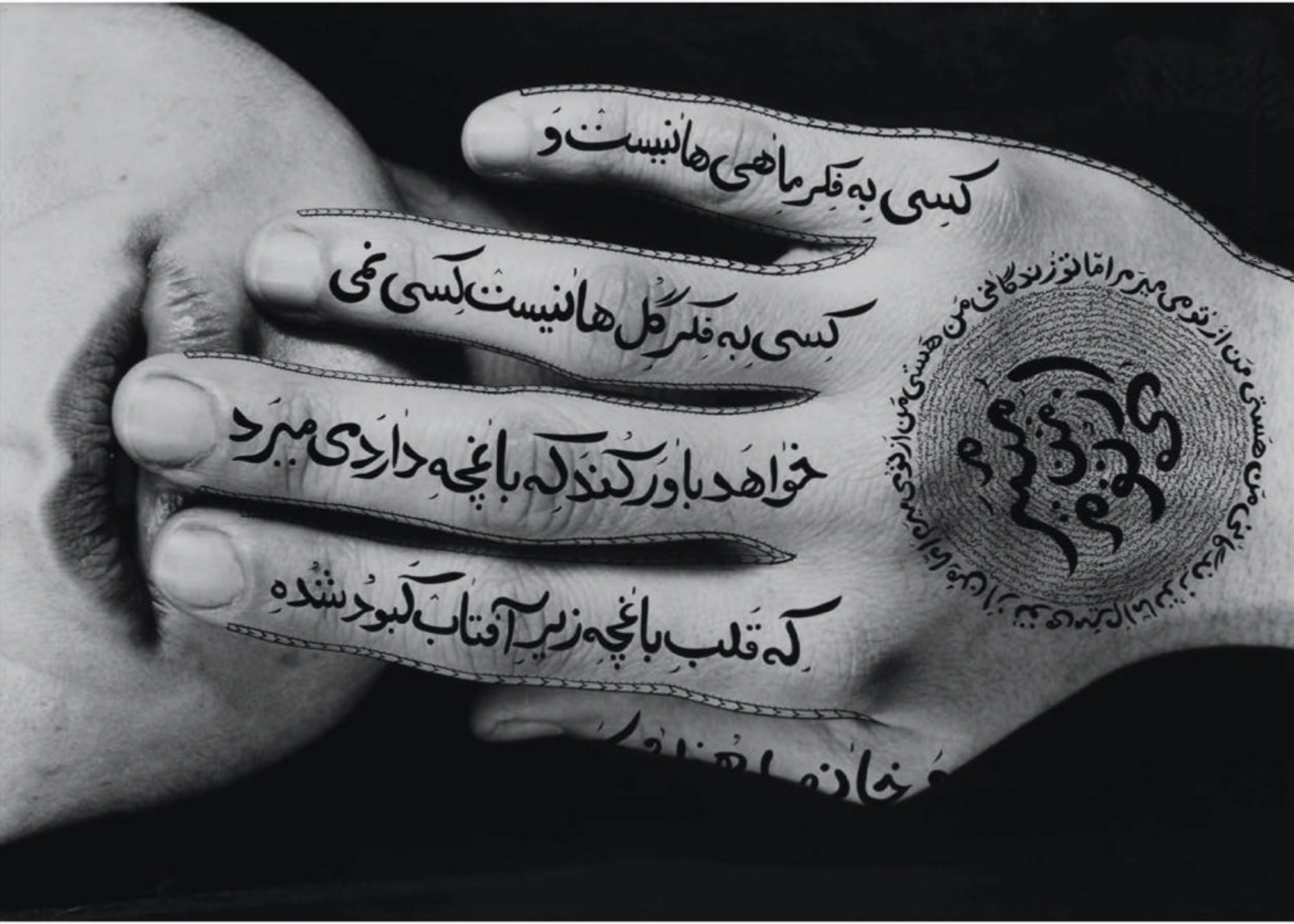
Speaking Volumes

An Iranian artist finds her voice in images

ART

Poetry infuses Persian culture, from its religious mysticism to its contemporary cinema. The Iranian-born, New York-based photographer and filmmaker **Shirin Neshat** believes that Iran's history of censorship turned people to metaphor because it conveys "what we cannot say overtly." Women, of course, have felt especially restricted. In *Untitled (Women of Allah)*, one from a series on view in a retrospective opening this month at the Hirshhorn Museum, Neshat inscribed selections from a poem by Forough Farrokhzad, the celebrated female Iranian poet, onto a hand pressed to gently closed lips. The passage compares a woman's desires to a garden dying in the summer heat. Because traditional Persian society compels women to passivity, a simple gesture can have expressive power, Neshat explains. "The hand, the gaze, the mouth—the things that are allowed to be seen are very poignant." –AMY CRAWFORD

PHOTOGRAPH BY LARRY BURNS / © SHIRIN NESHAT / COURTESY GLADSTONE GALLERY, NEW YORK AND BRUSSELS / HIRSHHORN MUSEUM, SI


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SMALL TALK

Beth Shapiro

A biologist at the University of California, Santa Cruz explains the science of de-extinction in *How to Clone a Mammoth*, out this month.

What animal would be the most fun to bring back to life?

The dodo. It's very silly-looking and has several weird traits: It can't fly, it retains juvenile characteristics and—obviously—it had no particular fear of humans as predators.

How long until de-extinction becomes a reality?

The answer depends on what you accept as "de-extinction." If you mean a pigeon born with some passenger pigeon traits, or an elephant with mammoth-like traits, it could happen within a few years to a decade. If you mean 100 percent mammoth, with all mammoth genes and behaviors, that will never happen.

Humans have long tinkered with life, what's the most disturbing example?

Hairless dogs. Apologies to anyone who thinks these creatures are wonderful, but when I see a hairless dog, all I can think is that I should smear it in sunscreen or wrap it in a blanket.

How will our relationship with nature change in the next century?

If we are going to maintain a rich and biodiverse world, we are going to need to become more active in our approach to conservation. It will not be sufficient to set aside parks or wild spaces. Why not provide populations a little bit of genomic assistance?

The Art of War

Researchers have decoded the deadly secret of a snake's venom

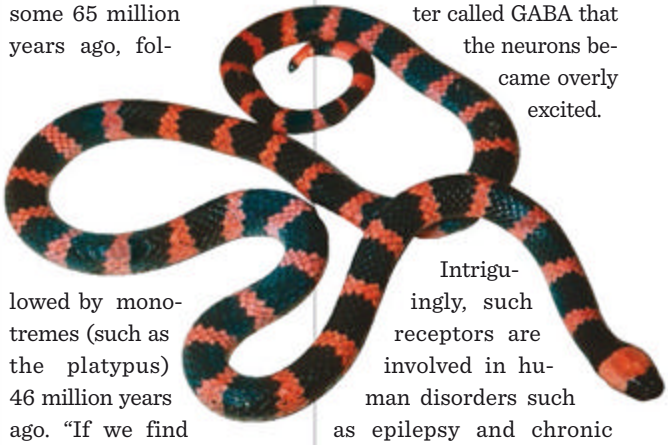
When he returned home to France after a stay in Costa Rica in 1983, Jean-Pierre Rosso carried back an unusual souvenir—a vial of deadly snake venom. Three decades later, after painstaking chemical and neurological analyses, Rosso and colleagues report that two toxins used by Costa Rican coral snakes act like no others, offering new insight into the astonishing array of chemical weapons that have evolved in the world's animals.

When Rosso's team, led by Pierre Bougis, a biochemist at France's National Center for Scientific Research, identified the six toxins within the venom, four of them worked as expected, causing paralysis in rodents and other effects. But two were puzzling because they triggered seizures instead.

The first step to understanding the mysterious toxins was to obtain more of the stuff to study in the lab. "I asked many times, 'Can we get more venom?'" recalls Bougis. But his Costa Rican collaborators, who had initially milked the rare reptile, always replied: "We don't have snakes." So the team had to synthesize the toxins, which took a full decade.

The planet is home to more than 100,000 animals with venom, much of which is only now being characterized by scientists. There are not only snakes, spiders and scorpions, but also snails, fish, caterpillars, lizards, squid and even a few mammals, including the platypus, the short-tailed shrew and the slow loris, the world's only venomous primate.

Because of the great variety, scientists suspect that the adaptation evolved not once but many times. A venomous jellyfish or sea anemone probably came first, maybe 500 million years ago, and venom arose in snakes some 65 million years ago, followed by monotremes (such as the platypus) 46 million years ago. "If we find complex life on other planets," says Bryan Fry, head of the venom evolution laboratory at the University of Queensland in Australia, "I bet there's going to be something venomous there."



Especially if that alien life depends on amino acids. Venom toxins, it turns out, are strings of these basic biological molecules, called peptides or proteins, depending on their size. Scientists speculate that the toxins in venoms weren't created by animals from scratch but are instead slightly altered versions of everyday peptides and proteins. A simple gene mutation can turn them into toxic weapons.

The French researchers don't know where the coral snake toxins come from, but once they got hold of enough material, they figured out where the toxins go. The team radioactively tagged the synthetic toxins and applied them to isolated bits of rat brain. The compounds bound so tightly to receptors for a neurotransmitter called GABA that the neurons became overly excited.

Intriguingly, such receptors are involved in human disorders such as epilepsy and chronic pain. Bougis is determined to continue studying the toxins' interactions with neurons, hoping it will lead to a new understanding of the disorders and perhaps treatments—even if the work takes another decade. "I am . . . in French, we say, *tête dure*," he laughs, "hard-headed." -EMILY ANTHES

ADAPTATION



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Natural Selections

Darwin transformed our understanding of the world. But an artist along on the famous voyage captured its wonders most vividly



The day Darwin climbed Patagonia's Mount Tarn, Conrad Martens painted it from across the bay (top). The desolation "exceeded all description," Darwin wrote, and the natives (above) were "half civilized, and proportionally demoralized."

In late 1833, with the HMS *Beagle* anchored in Montevideo and Charles Darwin hunting fossils ashore, a British landscape painter named Conrad Martens joined the crew. He's a "stone-pounding artist who exclaims in his sleep 'think of me standing upon a pinnacle of the Andes,'" Capt. Robert FitzRoy wrote in a letter to Darwin. "I'm sure you will like him." About halfway into a nearly five-year journey that would help him set the foundation for the theory of evolution, Darwin must have welcomed the new shipmate. With his 6- by 9-inch sketchbooks, pencils and watercolors, Martens, 32, detailed the dramatic vistas, and occasionally the inhabitants, in ways that words never could. "It's a remarkable view of the world. There's a freshness, absolutely. You just feel like you are there," says Alison Pearn, associate director of the Darwin Correspondence Project, which worked with the Cambridge University Digital Library to put Martens' images online. Darwin would have agreed. Martens left the voyage after just a year, when costs forced FitzRoy to downsize. But the three later met up in Sydney, where Darwin purchased some of Martens' paintings. One of them still hangs at his former estate, Down House.

-ELIZABETH QUILL

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Sheer Madness

Nylons were a craze when they debuted 75 years ago—but their run is over



Today nylon adds stretch to fishnets (worn here by Shelley Winters) and a variety of legwear.

I was born in the late '70s to a Scarsdale-bred baby boomer and I took my fashion cues from her. Like all little girls, I had my own style—brighter, weirder and more mothball-scented than my mother's Escada sweaters and J.Crew cowl necks. Yet I *fashioned* my outfits after hers: Vintage T-shirts tucked in and bloused, lots of belts, purses slung across my chest. By my teenage years, I'd grown out of most of these habits, except for one: nylons. My mother's generation constantly wore nylons (or "stockings," or the waist-covering "pantyhose," if you want to call them that, though I'd prefer you didn't) and thus I did too. They were sheer, nude, taupe, cream, tan and powder. I cannot recall a single holiday dinner or dance when I didn't have them on.

Nylons first went on sale in October 1939 in Wilmington, Delaware, home of their manufacturer, DuPont. Made from wool, cotton and silk, stockings had been around since before the invention of the knitting machine. But at a time when hemlines were rising yet modesty was still foremost, nylons offered a smoother, stronger and in some cases cheaper alternative to traditional hosiery. When stores stocked them nationally, 75 years ago this month, their popularity was massive. An estimated 64 million pairs were purchased in their first year on the market. Because DuPont never trademarked "nylon," "nylons" became synonymous with "hosiery." They were the American woman's greatest wardrobe staple. Then, of course, nylons hit a snag.

They were in short supply because the silky material was needed for the war effort (parachutes). Naturally, the paucity of nylons did what paucity always does: makes people want what they can't have. Some of the reactions were ingenious. Younger ladies compensated for their loss by drawing seams up the backs of their legs with an eye pencil (a practice I'm amazed hasn't seen a retro resurgence). Other reactions bordered on mania. Nylons sold on the black market for $20 a pair. Betty Grable auctioned a pair at a war bond rally for $40,000. When nylons went back into production in 1945, the newspaper headlines read like something out of the Darwin Awards: "Women Risk Life and Limb in Bitter Battle For Nylons."

It was reminiscent of the Dutch tulip craze, when, in the 17th century, a few tulip bulbs could pay for a house on an Amsterdam canal. Today, in a city once known as New Amsterdam, I can buy a bunch of tulips for $12 at my corner bodega. In that same bodega, I can also buy a pair of cheap nylons growing dusty on some unreachable shelf.

I know I am part of the reason they're gathering dust. I wore nylons straight through college—I had tons of them, curled in my sock drawer like oversized garlic knots—but I stopped when I hit proper adulthood. In the past decade or so, the style has been to go bare-legged or wear tights (which can be made of nylon but tend to be much thicker). "Hosiery" is no longer the most popular department in the store, if it's a department at all.

I must confess I hope they never come back. My personal style still leans vintage, but nylons—the childhood fashion I held onto the longest—have become the only one I refuse to revisit. They disguise a woman not for the sake of intrigue but for the sake of concealment. They made practical and sociological sense 75 years ago, but now I see them as a diversionary tactic, taking attention CONTINUED ON PAGE 20

ESSAY



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Steven Skiena, a professor at Stony Brook University and Charles B. Ward, an engineer at Google, have worked together to develop an algorithmic method, based on high-level math, of ranking historical figures according to their historical significance. Their rankings account not only for what individuals have done, but also for how well others remember and value them for it.

For this *Smithsonian Collector's Edition: The 100 Most Significant Americans of All Time*, we asked Skiena and Ward to separate figures significant to American history from the world population. We then developed categories and highlighted the most interesting choices. We hope our list will spark a few passionate discussions.

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CONTINUED FROM PAGE 16

away from a woman's real body. By smoothing over every bump, scratch and vein, how different are they, in spirit, from the corset? In going completely bare, women are saying that they're literally more comfortable in their skin. As we become more honest about who we are, more empowered to take ownership of our sexuality, we don't want some false taupe landscape wrapped around our thighs.

Alternatively, with bright cotton tights or blatantly patterned stockings, we're not trying to trick men into thinking we have different legs than we do. Women own the ruse. Of course my shins aren't naturally fuchsia. I am not part alien.

Having said all that, I am reasonably glad that nylons were once de rigueur. They certainly have more innovation and history behind them than most of our accessories. They've also served us well culturally. Think of Mrs. Robinson, rolling up her thigh-highs in *The Graduate*. And where would Melanie Griffith's character in *Working Girl* be without her nylons-and-sneaker look? Even my personal history with them was not for nothing. Last week, I noticed a run in my tights as I was leaving the house. Employing a trick my mother taught me before my high school prom, I dabbed clear nail polish at either end of the run to keep it from splitting farther. The nail polish worked just as well on my black tights as it used to work on my nude nylons.

Because clear always goes with everything. -SLOANE CROSLEY

Re-fighting Gallipoli

Russell Crowe's controversial new film views the battle from the Turkish side



Crowe's character has a mystical ability to locate hidden water.

The battle of Gallipoli, which began 100 years ago, epitomized the senseless carnage of World War I. British commanders conceived the campaign as a lightning strike against the Ottoman Empire, but the fighting dragged on for nine months and left 433,000 soldiers dead or wounded, including more than 28,000 Australian troops among the Allied forces.

The 1981 film *Gallipoli*, directed by Peter Weir, an Australian, depicts the tragedy of Australians heading into slaughter. Now a new Aussie film by Russell Crowe, *The Water Diviner*, radically shifts the perspective. Early in the movie, Ottoman troops clamber out of trenches to attack an Allied position, only to discover that the enemy has withdrawn overnight. As they watch battleships sail away in defeat, the Turks erupt in jubilation.

The film won the 2015 AACTA Award for best film (Australia's Oscar), but at a time of renewed violence stemming in part from perceived Western interference in Muslim lands, the depiction of a Muslim army celebrating the retreat of Western forces has unsettled certain viewers. Some Australian veterans' groups and historians have also accused Crowe of going too far—he has characterized the Gallipoli campaign as an unprovoked invasion of a "sovereign nation."

He shrugs off the criticism. "Growing up in Australia, you tend to see the battle from only one point of view," Crowe says. "I wanted to have the audience realize from the first take, 'Oh, this is not my grandfather's Gallipoli.'"

The Water Diviner tells the story of an Australian farmer, Joshua Connor, played by Crowe, who loses his sons at Gallipoli and travels there four years later to find their bodies. The film story was inspired by a letter from an official at the Imperial War Graves Commission, who mentions that "one old chap managed to get here from Australia, looking for his son's grave."

Australians view the battle of Gallipoli as their first great test on the world stage, and commemorate April 25, the date it began, as a day of remembrance. Like many Aussies, Crowe attends a dawn service to remember the sacrifice of the troops. If he can't find one, he says, "I'll create one of my own." But in making the movie he became aware of Turkish suffering. "I wasn't quite ready for the depth of the emotional connection," he says.

During a visit to a high school in Istanbul, officials told Crowe that the entire senior class had been sent to Gallipoli, and that "all but one of them perished." A door at the school was painted black to honor their sacrifice. It has remained that way ever since. "I started to feel how very important it was to see things from both sides," Crowe says.

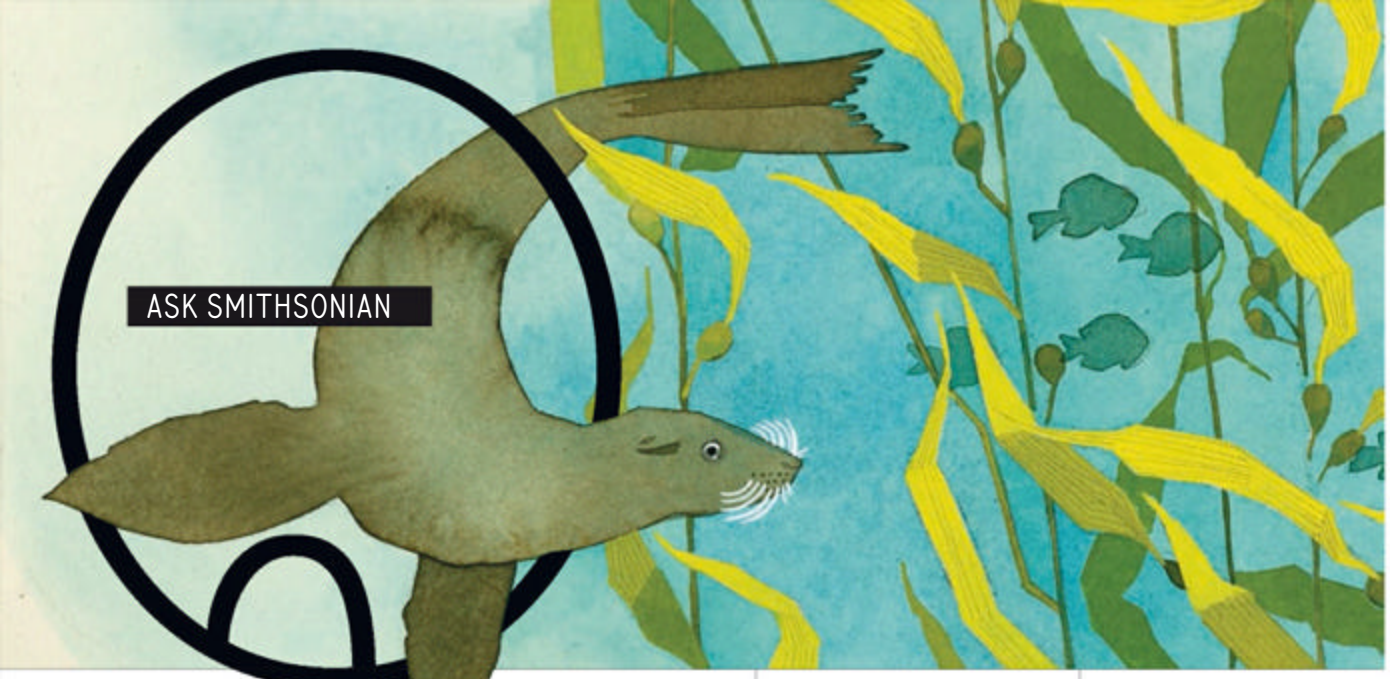
-JOSHUA HAMMER

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Your Questions Answered by Our Experts

How do diving animals that lack sonar, such as sea lions, detect their prey in water with poor visibility? Anthony Clayton, Wilmington, Delaware

The short answer is that they use their very sensitive whiskers, called vibrissae, to detect movement in the water. *Rebecca Miller, biologist, American Trail, National Zoo*

Are there any foods besides corn that have seeds that can be "popped"? Stan Zukowsky, Syosset, New York

Yes, there are. The key thing here is the relationship between the amount of moisture in the seed and the strength of the seed covering—the covering has to be weak enough to give way when the moisture expands under heat. In addition to corn, sorghum, amaranth and quinoa seeds have that felicitous relationship, so they will "pop," or puff, in a skillet. Happy snacking. *Cindy Brown, horticulturalist, Smithsonian Gardens*

Why could Hiroshima and Nagasaki be rebuilt so soon after they were destroyed by the A-bomb? Wouldn't the fallout remain unsafe for years? Nancy Davison, Sebastopol, California

Those two bombs were deliberately exploded high in the air; as a result, much of the radioactive debris was carried aloft and dispersed by the mushroom cloud. Moreover, the amount of fissionable material in both bombs was only about two pounds. In contrast, the meltdown at Chernobyl involved some two tons of material released at ground level with no mechanism for rapid dispersal. Today, Hiroshima and Nagasaki have background radiation levels well within the world average. *Tom Crouch, curator, aeronautics, National Air and Space Museum*

Why is there a lag between the winter and summer solstices and the coldest and warmest months of the year? Jennifer Latzgo, Fogelsville, Pennsylvania

Seasonal changes in sunlight don't instantly alter air temperatures because the earth's oceans and land masses are slower to cool down and warm up than the atmosphere. As the days shorten in winter, the oceans release heat they absorbed when the days were longer; as the days lengthen in summer, the oceans absorb the heat they will later release. The time lag between each solstice and the maximum high or low temperature varies with latitude and proximity to the oceans. *Andrew Johnston, geographer, Center for Earth and Planetary Studies, National Air and Space Museum*

Why are most homes no longer equipped with lightning rods? Paul Agathen, Washington, Missouri

Lightning rods have always been optional equipment; though lightning can strike erratically, tall trees or structures tend to protect shorter structures nearby. Buildings in open spaces are at higher risk and often have lightning rods. Today, homes at higher risk do have lightning-protection devices; they're just not as obvious as a rod jutting into the sky. *Harold Wallace, curator of electricity, National Museum of American History*

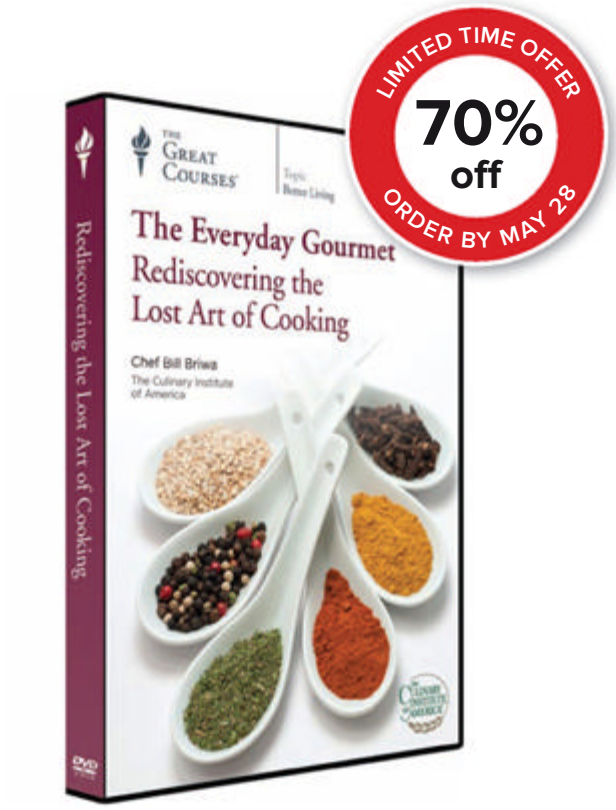
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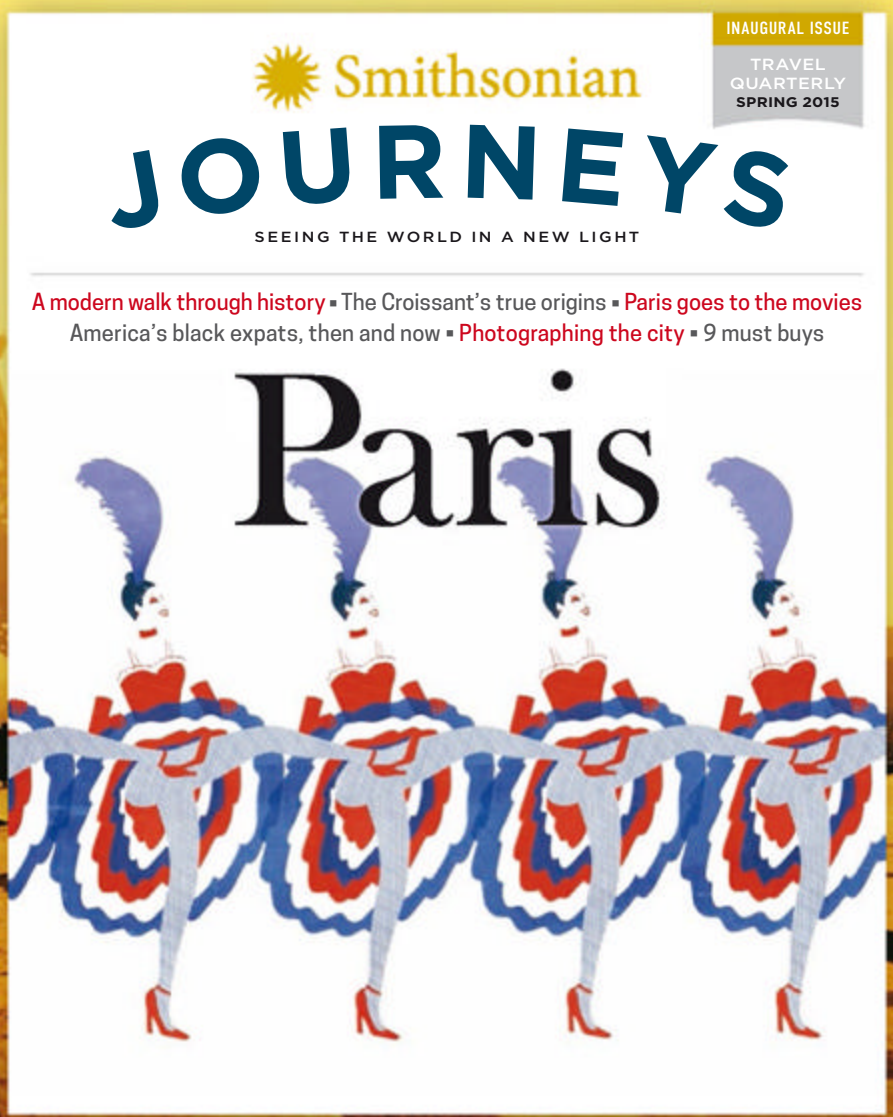
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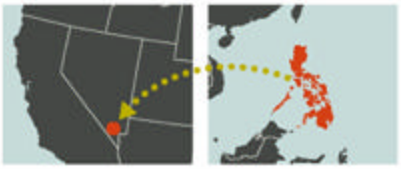
A wave of Filipino families in Las Vegas is putting a Pacific spin on fried chicken, hot dogs and Sin City itself

If you are a typical American, especially one who was born and raised here as we were, you probably believe—know—as we did that, Americans have a lock on fried chicken. Then we met Salve Vargas Edelman, who took us to her favorite Manila chicken joint. But this place, Max's Restaurant, wasn't in Manila. It was in Las Vegas, in a strip mall, a few miles past Caesars Palace, and it was there that we were fortuitously, deliciously, humbled.

Vargas Edelman, who was born in the Philippines, is a singer and bandleader who has toured the world. She is also a real estate agent, president of the Lions Club, host of a local television program called "Isla Vegas, the Ninth Island," and president of the Rising Asian Pacific Americans Coalition for Diversity, which she founded. It's at the RAPACD's cultural center, a one-story bungalow on the grounds of a neighborhood park, that we first met her.

"This is my baby," she said with a sweep of her arms, "17 years in the making." Years before, not long after moving to Las Vegas from San Francisco, where she lived after leaving the Philippines in 1980, Vargas Edelman noticed a sign for an Asian American center. "I followed it, looking for the building, but all there was was a sign," she recalled. Filipinos are a rapidly emerging demographic force in Las Vegas—between 2000 and 2010, the Filipino population in Nevada reportedly grew by 142 percent, so that there are now more Fili-

FLAVORS PHILIPPINES



BY SUE HALPERN AND BILL MCKIBBEN

photographs by Sam Morris

pinos than members of any other Asian nation in the state. When they ask for a community center, they get more than a sign: They get a building, too.

They also get Max's Restaurant of the Philippines, an institution back home with 160 outlets, which recently opened its first branch in Las Vegas. And with Max's comes its signature dish, Pinoy fried chicken: unbreaded, marinated in fish sauce and ginger, then fried till the skin turns cordovan and crisp and the butter-soft meat underneath slips off the bone.

It's at Max's that we next meet Vargas Edelman and a few of her friends, leaders in the Filipino community, each, like her, a model of civic engagement, the kind that Tocqueville celebrated in his 19th-century classic *Democracy in America*, the same kind that 20th-century sociologists said was done for. But those sociologists, clearly, hadn't been to Vegas. "The nice thing is, we brought our culture here," Vargas Edelman said. "The bayanihan system. It means unity, solidarity." A case in point: When Typhoon Haiyan cut across the central Philippines in November 2013, members of the Vegas Filipino community mobilized instantly, holding fund-raisers that continue to funnel money and goods back home. And speaking of home, they are also building 20 new homes in the area most devastated. They call the project "Vegas Village."

Filipino cuisine was Asian fusion before there was Asian fusion. It has borrowed and modified elements of Chinese, Spanish, Malaysian, Thai and Mongolian cooking.

We are dining on a whole Pinoy fried chicken and pancit—thin rice noodles tossed with shrimp that often comes with chicken and pork mixed in as well—and garlic rice (tastes like it sounds), and chicken adobo, a stew of onions, garlic and meat that is at once salty, tangy and sweet. *Adobo* is the Spanish word for marinade, but it's what is in the marinade that distinguishes Filipino adobo from any other: one of its main ingredients is vinegar, which gives the stew its distinctive, pleasant buzz. Adobo predates the colonization of the Philippines in the 16th century, when cooking with vinegar was an effective way to preserve meat. The conquerors gave adobo its name, but the colonists gave it its flavor.

Edna White puts some adobo on her plate with fried chicken and pancit, declares it "comfort food" and mentions that she's been up all night packing 20 large containers of clothes and supplies for typhoon victims. It's just "a little something" she's been doing on the side for months while running a print shop and working part time at a local hospital as a nurse, ever since the storm devastated the town where she grew up and where her sister still lives.

"After the typhoon, I tried to find her for four days. I'd call every night and no one would pick up," White recalled. "Eventually my sister was able to get to an area about two hours away from where she lived that had not been hit so hard and I was finally able to get through to her. I was so relieved. She said she had not eaten in three days. I asked her why she didn't eat coconuts, and she told me that all the trees had been ripped out of the ground and everything was underwater and there were no coconuts. I told her not to go anywhere, to stay in that town and wait and I would send her $200. I told her that when she got it, to take the money and buy as much rice as she could and then go back and share it with everyone. Because of course you can't be eating when no one else is.

"At first I was just trying to help the people I knew, sending money and candles and matches—they didn't have electricity—but there were so many people who needed help and I was running out of money, so I went to a Republican Party meeting and the chairman let me talk and ask for help. People gave me $10, $20, even $100. I sent it over there and told people to take pictures of what they bought with it: chicken, rice noodles, hot dogs."

Hot dogs figure in Filipino cuisine, though in a roundabout way. It starts with spaghetti, which was adapted after being introduced to the Philippine archipelago by the European traders who sailed along the South China Sea. Yet while it may look like standard-issue, Italian-style spaghetti topped with marinara, prepare to be surprised. Filipino spaghetti is sweet—in place of tomato sauce Pinoy cooks use banana ketchup, developed during World War II when tomatoes were in short supply—and it is chock-full of not meatballs, but sliced hot dogs.

Which is to say that Filipino cuisine was Asian fusion before there was Asian fusion. It has borrowed and modified elements of Chinese, Spanish, Malaysian, Thai and Mongolian cooking, to name just a few of its influences.

"We use rice noodles instead of the wheat noodles that the Chinese use," explained Jason Ymson, the afternoon we met him and about 25 other Filipino community leaders for lunch at the Salo-Salo Grill & Restaurant. Ymson is the assistant chef at Twin Creeks steakhouse in the Silverton Casino, where he has been slowly working Filipino tastes into his pan-Asian creations. "Siopao—our steamed buns with meat inside—are a direct transliteration from the Chinese. Flan is Spanish but we have leche flan. Adobo is a common derivative of Chinese soy sauce chicken. Filipino cuisine is a hybrid, so there is a lot of leeway to play with it."

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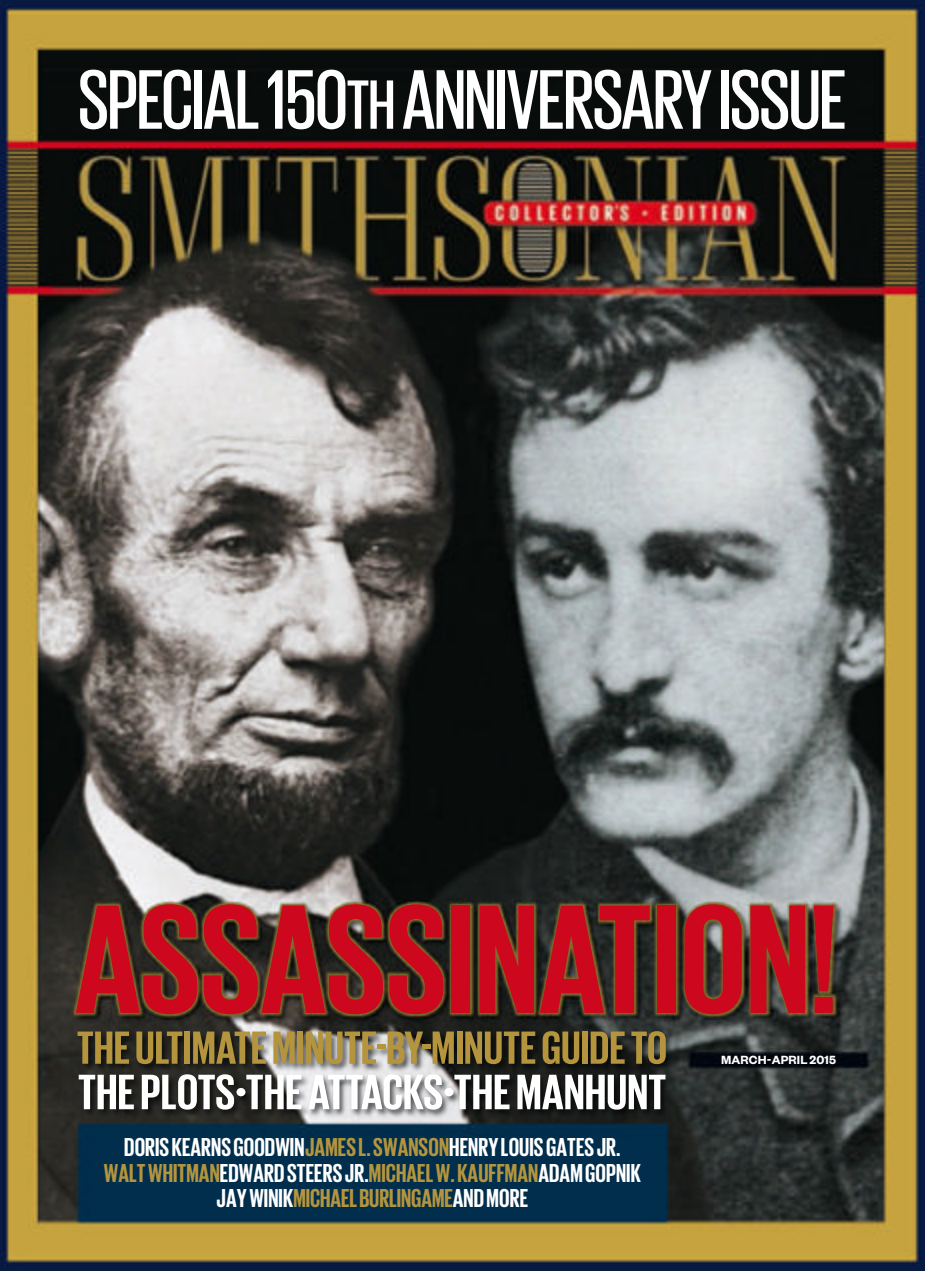
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Even so, "Filipino food is hard," observed Rudy Janeo, a private caterer and chef at an Italian restaurant. "People don't order it because they don't know it, and they don't know it because they don't order it. Serve a fish with the head on and no one wants to eat it."

"Because Americans haven't been exposed to Filipino cuisine, the idea is to work in the Filipino elements bit by bit until you have a full-blown dish," Ymson added. "The most challenging part is nailing the description correctly so you don't scare people off." He passes a dish of barbecued squid down the table, which we are instructed to eat two-fisted, skewered on a fork and carved with a spoon, a trick we have yet to master.

Jason Ymson is a pioneer, not only for his mission to introduce Filipino tastes into the mainstream American palate, but also because as a second-generation Filipino, born and raised in Las Vegas, he has made the transition into the mainstream himself.

"Back in the '80s—I was born in 1984—Filipinos were a small niche community. When you went to a party you always saw the same people. As my generation began to assimilate, we moved out into other communities. The biggest evidence of assimilation is the accent. My mom is very traditional. She has been here since the 1970s and still has a thick accent. My father, who assimilated into American culture, has no accent. When I was first going to school, he would do my English homework too."

Unlike Ymson, the typical Vegas Filipino has moved to the city from somewhere else in the United States. The community's phenomenal growth is an aggregation, a resettlement from one part of America to another.

Rozita Lee, who in 2010 was appointed by President Barack Obama to his Advisory Commission on Asian Americans and Pacific Islanders, has had a front row seat to this in-migration. She moved in 1979 from Hawaii to Las Vegas to join her husband, who had a medical practice here at the time. As we sipped bright orange cantaloupe juice at Salo-Salo, she took a pen from her handbag and drew on the paper tablecloth.

"First the casino and hotel workers came, followed by the entertainers and the professionals. Then Filipinos from other parts of the country, especially the Northeast, started to retire here. In the '70s and '80s, you got the middle class. In the 2000s, you got the rich. And then, after the economic downturn, around 2008, you started to see those who were not doing well, especially in California, come here for jobs." When Lee stopped drawing, she had made several parallel lines. The point, she said, is that these different groups of Filipinos didn't necessarily intersect.

If that was the rule, the exception was Seafood City, a colossal supermarket not far from the Las Vegas Strip, which was bustling on a Sunday morning as shoppers young, old and mostly Filipino snacked on siopao and lumpia (fried spring rolls filled with ground pork, onions and carrots) as they pushed carts along aisles filled with foods whose names were as exotic to us as the items themselves. There was bibingka, a deep purple, sweet rice-based dessert; and ginataan, a dessert made from coconut milk, potatoes, bananas and tapioca. There were duck eggs whose shells were crayon red, kaong (palm fruit in syrup), taro leaves in coconut cream, cheesy corn crunch and racks of shrimp paste, dried herring in oil, dried salted rabbitfish, quail eggs in brine and bottles of banana sauce. And that was before we got to the frozen food case, filled with birch flower, frozen banana leaves, squash flower, horseradish fruit, grated cassava, macapuno ice cream and cheese ice cream. And then there was the fish—moonfish,

He passes a dish of barbecued squid down the table, which we are instructed to eat two-fisted, skewered on a fork and carved with a spoon, a trick we have yet to master.



Off duty, chef Jason Ymson prepares bistek, a Filipino steak dish, with his son, Enzo.



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Gilbert Stuart, *George Washington (Lansdowne Portrait)*, 1796. Gift to the nation through the generosity of the Donald W. Reynolds Foundation, National Portrait Gallery, Smithsonian

mudfish, pony fish, Bombay duck fish, belt fish, blue runner, redtail fusilier, Japanese amberjack, cabria bass, yellow stripe, tupig, milkfish. We could go on but won't, since milkfish is the national fish of the Philippines.

Milkfish is also the centerpiece of bangus, a dish that has spawned its own festival, in Dagupan City, where people compete in deboning contests and costumed street dancers re-enact the milkfish harvest. The way it is served at Salo-Salo—wrapped in banana leaves and steamed with onions, ginger and tomatoes—is the way it's prepared in Manila and by islanders in Negros Occidental. In other regions it may be grilled or broiled. Pinaputock na bangus—what we are having—is meaty and mildly piquant; the banana leaves have permeated the fish.

Now we are sampling laing—taro leaves cooked in coconut milk with grilled shrimp and chilies that are as green a vegetable as we're likely to see. Amie Belmonte, who runs Fil-Am Power, an organization she started with her husband, Lee, and other community leaders to translate the Filipinos population surge into nonpartisan political clout, recalled how when she first moved to Las Vegas to run the city's department of senior services, she used foods she'd grown up with to introduce herself. "The people I worked with thought I was Hawaiian. I had to explain that though I grew up in Hawaii, I was Filipino, from the Philippines. So I brought in lumpia and pancit and shared it. Food is the avenue into a culture."

That has turned out to be true for second- and third-generation Filipino-Americans, too. As Jing Lim, who grew up in a Filipino community in Juneau, Alaska, told us, "Pretty much everything my three boys know about Filipino culture comes from food and family. And by family I don't just mean the immediate family. I mean first cousins, second cousins, fifth cousins."

"Our mainstay, as a culture, is our food," said Roger Lim, Jing's husband. "That's what brings families together. We always eat family-style."

A cuisine is created not only by ingredients and methods and tastes, but also from how that food is consumed and shared. For Filipinos, that cuisine starts and ends with family.

Family—connection—is what brought many Filipinos to the United States in the first place, often through a process called "petitioning," where one family member could petition the American government to allow another family member to follow. After Edna White married an American and moved to the States—first to Oregon, then to Nevada—she petitioned for her mother to join her. For Salve Vargas Edelman it was her mother who petitioned her, having been petitioned herself by another daughter who had married an American serviceman. "Because I was single, the family decided I should be the one to take care of our mother, who was not well," Vargas Edelman said. "Part of our culture is that we take care of our elders. My generation didn't even know what rest homes were. It's part of our religion, too. We believe in the Ten Commandments: Honor your mother and father."

And it is not just parents. "We have this very nice Filipino tradition of respecting our elders," Vargas Edelman's friend, Cynthia Deriquito, added. "All your siblings, if they respect you, they follow you. From your profession down to how you live your life. And then our children are kind of copying it. Whatever the eldest does is mimicked."

Deriquito, a board member of Fil-Am Power, is a former nurse—a profession practiced by many Filipino Americans, including her brother, two sisters, daughter and niece. "Since I was the first born and my dad died at 47, I sent my three siblings to nursing school. It's not unusual. It's not heroic. It's just what you do."

Another thing you do, especially at Max's once you have finished your fried chicken, is have halo-halo for dessert. Imagine an ice-cream sundae, but instead of chocolate or vanilla, the ice cream is purple and made from yams, and instead of whipped cream, there is evaporated milk, and instead of nuts, there are boiled beans—garbanzo, white and red beans. Now add some coconut, palm fruit, pounded rice flakes, jackfruit and shaved ice. In Tagalog, the main language of the Philippines, *halo-halo* means "mix-mix" or "hodgepodge." This hodgepodge is sweet and rich, different yet just at the edge of familiar. It reminded us of what Rhigel Tan told us that afternoon at Salo-Salo. Tan, a professor of nursing at the University of Nevada, Las Vegas, is also a founder of Kalahi, an 80-person folkloric ensemble that performs traditional Filipino dances, songs and stories. "I believe in the beauty of diversity," he said, "but I don't believe in the melting pot. I believe in the stew pot. In the melting pot you lose your identity. In the stew pot, you're the potato, I'm the carrots, and everyone knows who they are."

Imagine an ice cream sundae, but instead of chocolate or vanilla, the ice cream is purple and made from yams, and instead of whipped cream, there is evaporated milk.

Get your fill of Sam Morris' delicious halo-halo photos at Smithsonian.com/filipino


THE

BODY SHOP

AT A LABORATORY IN NORTH CAROLINA, SCIENTISTS ARE WORKING FURIOUSLY TO CREATE A FUTURE IN WHICH REPLACEMENT HUMAN ORGANS ARE GROWN ON DEMAND



BY Matthew Shaer

PHOTOGRAPHS BY **JEREMY M. LANGE**

On the second floor of the Wake Forest Institute for Regenerative Medicine, not far from the elevator bank, is a collection of faded prints depicting great moments in medical history. In one, an ancient Babylonian pharmacist holds aloft a vial of medicine. Another shows the Greek physician Hippocrates tending to a patient in the fifth century B.C. The prints were doled out to doctors half a century ago by the pharmaceutical company Parke-Davis, which touted them as a historical highlight reel. But it's not hard to read their presence at Wake Forest, home to perhaps the largest concentration of medical futurists on the planet, as the ultimate in-joke: *Can you believe how far we've come?*

When I visited the institute, in the old North Carolina tobacco town of Winston-Salem, I passed airy laboratories where white-coated staffers glided back and forth across a tiled floor. On one table, arranged as if for an art exhibit, lay spidery casts of kidney veins, rendered in hues of violet and indigo and cotton candy. Down the hall a machine zapped sporadic electric currents through two sets of muscle tendons, one cut from a rat, the other engineered from biomaterials and cells.

A researcher named Young-Joon Seol met me at the door to a room marked "Bioprinting." Young-Joon, tousled-haired and wearing plastic-framed eyeglasses, grew up in South Korea and trained in mechanical engineering at a university in Pohang. At Wake Forest, he is part of a group that works with the lab's custom-built bioprinters, powerful machines that operate in much the same way as standard 3-D printers: An object is scanned or designed using modeling software. That data is then sent to the printer, which uses syringes to lay down successive coats of matter until a three-dimensional object emerges. Traditional 3-D printers tend to work in plastics or wax. "What's different here," Young-Joon said, nudging his eyeglasses up his nose, "is that we have the capability to print something that's alive."

He gestured at the machine to his right. It bore a passing resemblance to one of those claw games you find at highway rest stops. The frame was heavy metal, the walls transparent. Inside were six syringes arranged in a row. One held a biocompatible plastic that, when printed, would form the interlocking structure of a scaffold—the skeleton, essentially—of a printed human organ or body part. The others could be filled with a gel containing human cells or proteins to promote their growth.

As the scaffold is being printed, cells from an intended patient are printed onto, and into, the scaffold; the structure is placed in an incubator; the cells multiply; and in principle the object



Atala leans against a custom-built 3-D bioprinter. Seventy-four percent of Americans think bioengineered organs are an "appropriate use" of technology. The number of 3-D printers used by medical centers is expected to double in the next five years.

"For me, the demand wasn't an abstract thing. It was very real, it was heartbreaking and it drove me. It drove all of us to find new fixes."

is implanted onto, or into, the patient. In time, the object becomes as much a part of the patient's body as the organs he was born with. "That's the hope, anyway," Young-Joon said.

Young-Joon had programmed one of the printers to begin the process of creating the scaffold for a human ear, and the room filled with a comforting electronic thrum broken only by the occasional gasp from the printer—the release of the compressed air that kept it working. Peering through the glass case, I could see the scaffold coming into being by degrees—small, delicate, extremely *earlike*. Because the process would take hours to complete, Young-Joon handed me a finished version to handle. It was light; it rested on my palm like a butterfly.

The external structure of the ear is one of the first structures that the institute at Wake Forest (and other research centers) have tried to master, as a stepping stone toward more complicated ones. Wake Forest staffers have implanted bioprinted skin, ears, bone, and muscle on laboratory animals, where they grew successfully into the surrounding tissue.

To evangelists of bioprinting, who are increasing—the number of 3-D printers shipped to medical facilities is expected to double in the next five years—the trials are a harbinger of a world that is only now coming into focus: a world where patients order up replacement parts for their body the same way they used to order a replacement carburetor for their Chevy.

"Think about it like the Dell model," said Anthony Atala, a pediatric urologist and the institute's director, referring to the computer company's famous "direct" relationship model between consumer and manufacturer. We were sitting in Atala's office on the fourth floor of the research center. "You'd have companies that exist to process cells, create constructs, tissue. Your surgeon might take a CT scan and a tissue sample and ship it to that company," he said. A week or so later, an organ would arrive in a sterile

container via FedEx, ready for implantation. *Presto, change-o*: A new piece of me—of you—made to order.

"What's interesting is that there are no real surgical challenges," Atala said. "There are only the technological hurdles that you've got to overcome to make sure the engineered tissue functions correctly in the first place."

We're getting close, with "simple" organs like skin, the external ear, the tube-like trachea. At the same time, Atala can't help but look to what might come next. At his most sanguine, he likes to envision a vast bioprinting industry capable of cranking out big and complex organs without which the body would fail, like the liver or the kidney. An industry that could make traditional transplants—with their long, often fatal wait times and the ever-present risk of organ rejection—completely obsolete.

It would be a full-on medical revolution. It would change everything. And if he's right, Wake Forest, with its purring bioprinters and fleshy ears and multicolored veins and arteries could be where it all starts.

The idea that a broken piece of ourselves might be replaced with a healthy piece, or a piece from somebody else, stretches back centuries. Cosmas and Damian, patron saints of surgeons, were alleged to have attached the leg of a recently deceased Ethiopian Moor onto a white Roman in the third century A.D., a subject depicted by numerous Renaissance artists. By the 20th century, medicine had at last begun to catch up with the imagination. In 1905 the ophthalmologist Eduard Zirm successfully cut a cornea from an injured 11-year-old boy and emigrated it into the body of a 45-year-old Czech farm laborer whose eyes had been damaged while he was slaking lime. A decade later, Sir Harold Gillies, sometimes called a founding father of plastic surgery, performed skin grafts on British soldiers during World War I.

But the first successful transplant of a major organ—an organ vital to human function—didn't happen until 1954, when Ronald Herrick, a 23-year-old from Massachusetts, donated one of his healthy kidneys to his twin brother, Richard, who was suffering from chronic nephritis. Because the identical Herrick twins shared the same DNA, Joseph Murray, a surgeon at Peter Bent Brigham Hospital (today known as Brigham and Women's), was convinced he'd found an end-run around the problem of organ rejection.

In his autobiography, *Surgery of the Soul*, Murray recalled the moment of triumph. "There was a collective hush in the operating room as we gently removed the clamps from the vessels newly attached to the donor kidney. As blood flow was restored, Richard's new kidney began to become engorged and turn pink," he wrote. "There were grins all around." With the Herricks, Murray had proved an essential point about our biological myopia, an insight that drives so much of today's cutting-edge bioengineering: There is no substitute for using a patient's own genetic material.

As surgical science improved along with the immunosuppressive treatments that allowed patients to accept foreign organs, what once seemed all but out-of-reach became reality. The first successful pancreas transplant was performed in 1966, the first heart and liver transplants in 1967. By 1984, Congress had passed the National Organ Transplant Act, which created a national registry for organ matching and sought to ensure that donor organs were being fairly distributed. In hospitals across the country, doctors broke the news as gently as they could—*The supply simply is not meeting the demand, you'll have to hang on*—and in many cases they watched as patients died waiting for their names to tick to the top of the list. This basic problem has not gone away. According to the U.S. Department of Health & Human Services, 21 people die each day in this country alone waiting for an organ. "For me, the demand wasn't an abstract thing," Atala told me recently. "It was very real, it was heartbreaking, and it drove me. It drove all of us to find new fixes."

Atala, who is 57, is thin and slightly stoop-shouldered, with a shock of brown hair and an easy affability—he encourages everyone to call him Tony. Born in Peru and raised in Florida, Atala earned his M.D. and specialized training in urology at the University of Louisville. In 1990, he received a two-year fellowship with the Harvard Medical School. (Today, at Wake Forest, he still blocks off at least one day a week to see patients.) At Harvard he joined a new wave of young scientists who believed one solution to the organ donor shortage might be the creation, in a laboratory, of replacement parts.

Among their first big projects was to try to grow a human bladder—a relatively big organ, but a hollow one, fairly simple in its function. He used a suturing needle to stitch together a biodegradable scaffold by hand. Later, he took urothelial cells from the bladder and urinary tract of a potential patient and multiplied them in the lab, then he applied the cells to the structure. "It was like baking a layer cake," Atala told me. "We did it one layer at a time. And once we had all the cells seeded, we then put them back into an incubator, and we let it cook." Within a few weeks, what emerged was a little white orb, not so dissimilar-looking from the real thing.

"You've got to think, 'I only have this much time, so what's going to make the greatest possible impact on the most lives?'"

Between 1999 and 2001, after a series of tests on dogs, custom-grown bladders were transplanted into seven young patients suffering from spina bifida, a debilitating disorder that was causing their bladders to fail. In 2006, in a much-heralded paper in the *Lancet*, Atala announced that, seven years on, the bioengineered bladders were



A device that one day might test drugs circulates a blood substitute to tiny lab-grown organoids that mimic the function of the heart, liver, lungs and blood vessels.

working remarkably well. It was the first time lab-grown organs had been successfully transplanted in humans. "This is one small step in our ability to go forward in replacing damaged tissues and organs," Atala said in a press release at the time, echoing the words of Neil Armstrong. It was a representative example of one of Atala's primary gifts. As David Scadden, the director of the Center for Regenerative Medicine at Massachusetts General Hospital and the co-director of the Harvard Stem Cell Institute, told me, Atala has "always been a visionary. He's always been quite bold, and quite effective in his ability to draw attention to the science."

Bladders were an important milestone, but they didn't rank particularly high in terms of patient demand. Moreover, the multi-stage approval process required by the U.S. Food and Drug Administration for such procedures can take time. Today the bladders Atala engineered haven't yet received approval for widespread use. "When you're thinking about regenerative medicine, you've got to be thinking not just about what's possible, but what is needed," Atala told me. "You've got to think, 'I only have this much time, so what's going to make the greatest possible impact on the most lives?'"

For Atala, the answer was simple. About eight out of ten patients on a transplant list needs a kidney. According to a recent estimate, they wait an average of four and a half years for a donor, often in serious pain. If Atala really wanted to solve the organ shortage crisis, there was no way around it: He'd have to deal with the kidney.

From its origins in the early 1980s, when it was viewed largely as an industrial tool for building prototypes, 3-D printing has grown into a multibillion-dollar industry, with an ever-widening range of potential applications, from designer shoes to dental crowns to homemade plastic guns. (Today, you can walk into an electronics store and purchase a portable 3-D printer for less than $500.) The first medical researcher to make the leap to living matter was Thomas Boland who, while a professor of bioengineering at Clemson University, in South Carolina, in 2003 filed for a patent on a customized inkjet printer capable of printing human cells in a gel mixture. Soon, researchers like Atala were tinkering with their own versions of the machine.

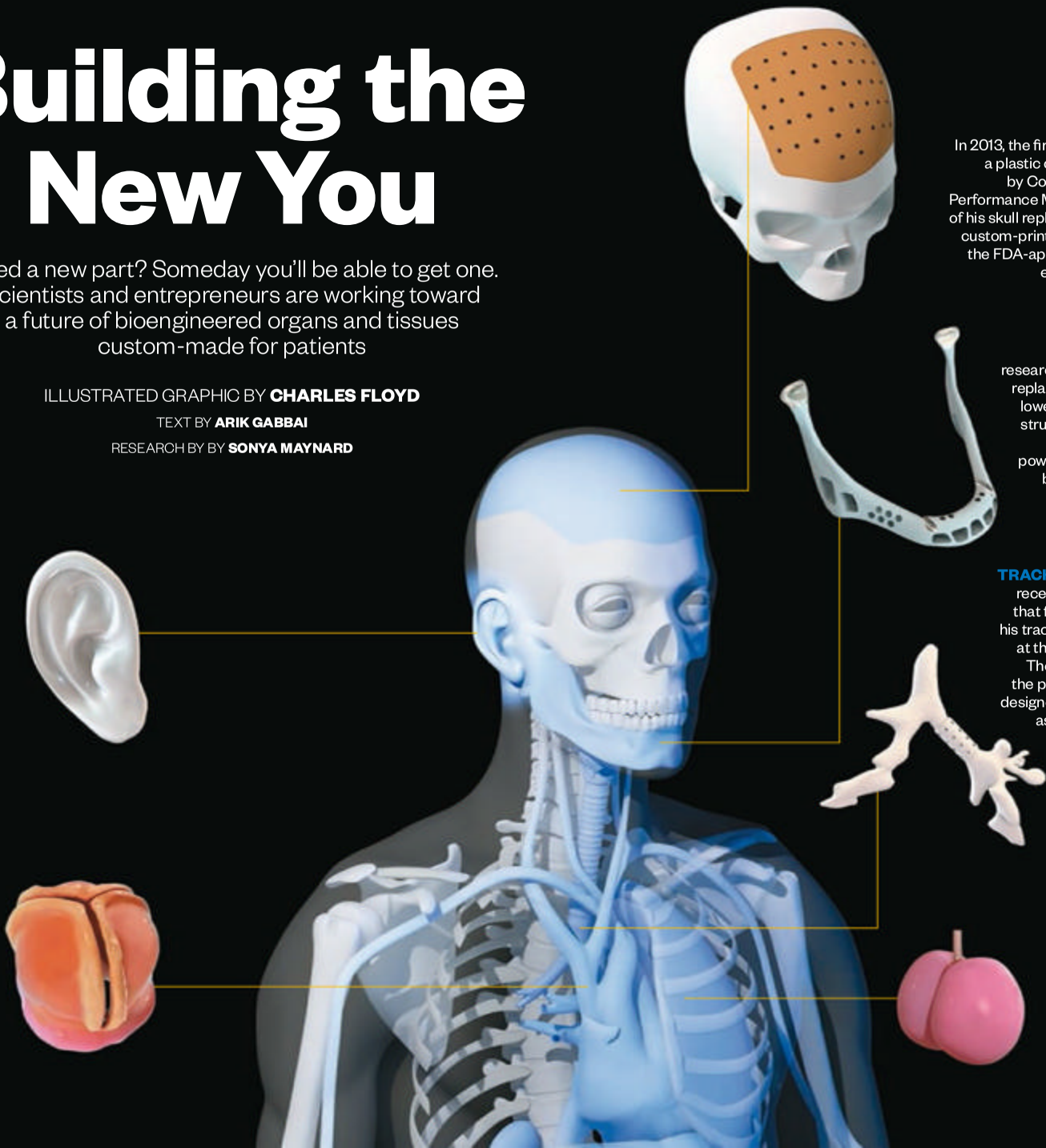
For Atala, the promise of bioprinting had everything to do with scale. Though he'd successfully grown an organ in a lab and transplanted it into a human, the process was incredibly time-intensive, precision was lacking, reproducibility was low, and the possibility of human error omnipresent.

At Wake Forest, where Atala be-

Building the New You

Need a new part? Someday you'll be able to get one. Scientists and entrepreneurs are working toward a future of bioengineered organs and tissues custom-made for patients

ILLUSTRATED GRAPHIC BY **CHARLES FLOYD**
TEXT BY **ARIK GABBAI**
RESEARCH BY BY **SONYA MAYNARD**



CRANIAL PLATE In 2013, the first U.S. patient to receive a plastic cranial implant designed by Connecticut-based Oxford Performance Materials had 75 percent of his skull replaced. The company has custom-printed over 500 versions of the FDA-approved device; the holes encourage tissue growth.

MANDIBLE In 2012, researchers in the Netherlands replaced a woman's diseased lower jaw with a 3-D-printed structure of heated titanium powder, fused by a high-powered laser and coated in biocompatible ceramics. Within a day she could speak and swallow.

TRACHEA A 3-month-old boy received a 3-D-printed splint that fit over a weak section of his trachea in a 2012 procedure at the University of Michigan. The splint has expanded as the patient has grown, and it's designed to eventually dissolve as his cells grow around it.

LUNGS In research on lab rats, Laura Niklason at Yale implanted engineered lungs capable of exchanging oxygen and carbon dioxide—a first. She says it'll be a "couple of decades" before such lungs, perhaps derived from a patient's stem cells, are transplanted into a person.

EAR To treat deformities of the outer ear, Jason Spector at Cornell prints an ear-shaped mold, fills it with a gel containing bovine cartilage cells and collagen from rat tails, then later removes the tissue and lets it grow before attaching it to an animal. Next up: human cells.

HEART VALVE At Rice University, K. Jane Grande-Allen and colleagues are trying to grow replacement valves from a patient's own cells. They plan to embed two types of live heart valve cells into a gel-and-fiber scaffold. The idea is to get the cells to fill and cover the gel and help form a working valve. Grande-Allen predicts that such a bioengineered part may be ready to test in heart patients within a decade.

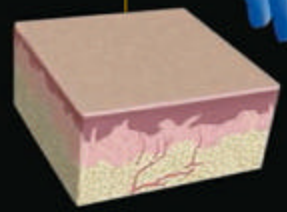
KIDNEY Tiny kidneys engineered by Harald Ott at Massachusetts General Hospital filtered blood and discharged urine when transplanted into rats. Most promising, the experiment succeeded partly because some of the lab-grown cells organized themselves effectively within the kidney on their own.



INTERVERTEBRAL DISK When one of the shock-absorbing disks between our vertebrae breaks down, pain ensues. Current treatments have flaws; spinal fusion, for instance, hinders movement. Robby Bowles at the University of Utah is engineering disks using sheep cells. The goal is to restore mobility as well as ease pain.

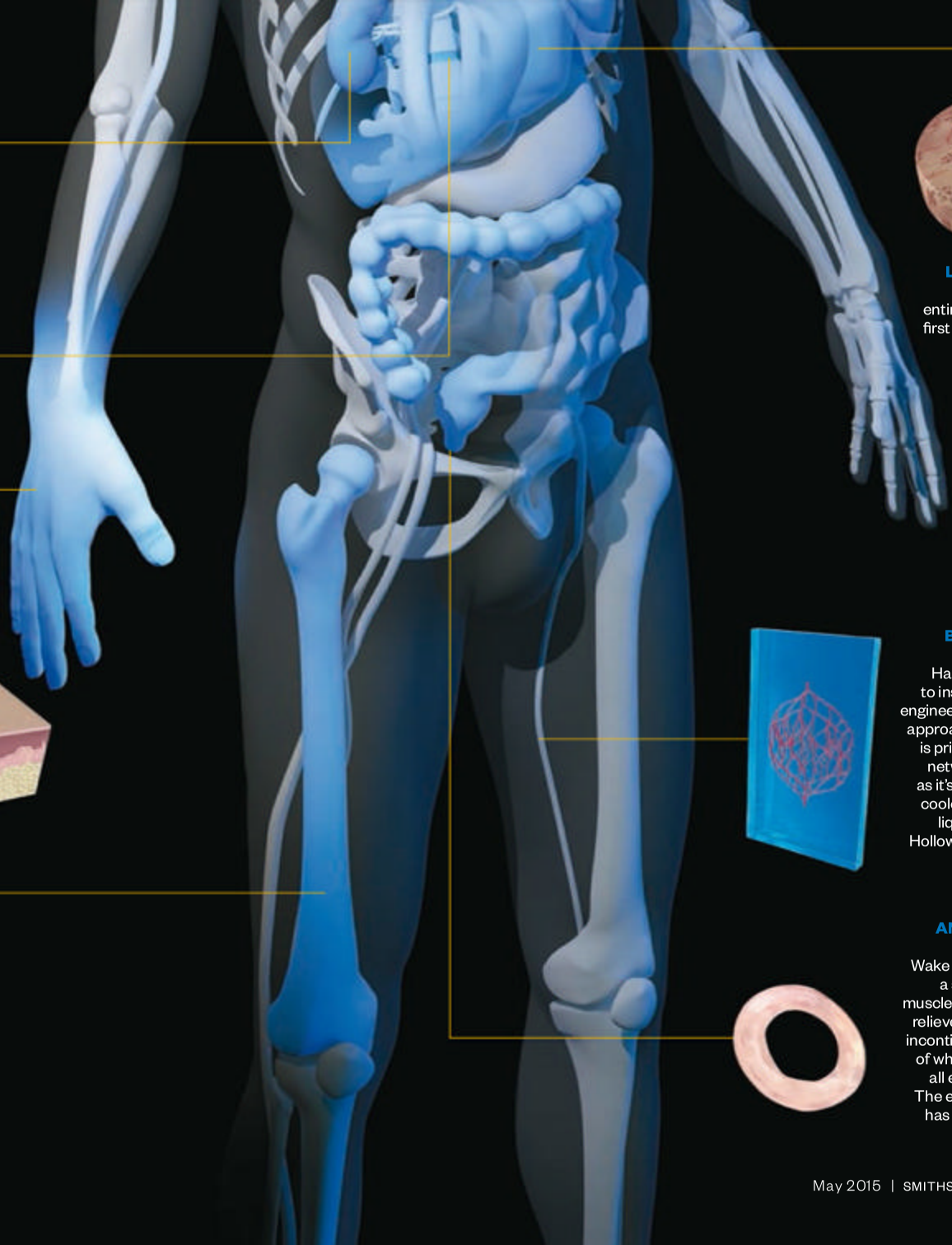


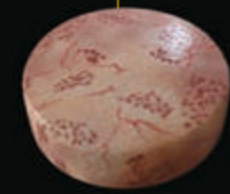
SKIN Medical researchers look forward to printing skin cells directly onto the body, filling a wound exactly. John Jackson at Wake Forest applied skin a centimeter deep onto pigs, with positive results. He hopes to try the treatment on people within five years.



BONE (FEMUR) EpiBone, in New York, grows bone tissue in specialized bioreactors (See "The Skeleton Crew," p. 43). The company implanted lab-grown jawbones into pigs and now is testing more complex facial bones. Officials hope to try engineered bone tissue in people in three years.







LIVER No one has bioengineered an entire human liver. In a first step, Wake Forest engineers grew a miniature liver an inch in diameter and weighing a fifth of an ounce. And California-based Organovo is selling 3-D-printed human liver tissues (above) for testing drugs.

BLOOD VESSELS Jennifer Lewis, at Harvard, studies how to install vessels within engineered organs. In one approach, a "fugitive" gel is printed as a vascular network into an organ as it's assembled; when cooled, the gel turns to liquid and pours out. Hollow channels remain.

ANAL SPHINCTER Khalil Bitar, now at Wake Forest, developed a sphincter made of muscle and nerve cells to relieve urinary and fecal incontinence, some form of which plagues half of all elderly Americans. The engineered muscle has been successfully implanted in mice.

came the institute's founding director in 2004, he began experimenting with printing skin, bone, muscle, cartilage and, not least, kidney structures. Within a few years he was confident enough in his progress to show it off. In 2011, Atala gave a TED Talk on the future of bioengineered organs that has since been viewed more than two million times. Wearing pleated khakis and a courtly striped button-down shirt, he spoke of the "major health crisis" presented by the organ shortage, partly a result of our longer lifespans. He described the medical challenges that innovation and dogged lab work had summarily conquered: devising the best biomaterials for use in scaffolds, learning how to grow organ-specific cells outside the human body and keep them alive. (Some cells, he explained, like those of the pancreas and the liver, remained stubbornly difficult to grow.)

And he spoke about bioprinting, showing a video of a few of his printers at work in the lab and then revealing a printer behind him on the stage, busy building a pinkish spherical object. Toward the end of his talk, one of his colleagues emerged with a large beaker filled with a pink liquid.

While the crowd sat in silence, Atala reached into the beaker and pulled out what appeared to be a slimy, oversized bean. In a masterly display of showmanship, he held the object forward in his cupped hands. "You can actually see the kidney as it was printed earlier today," he said. The crowd broke into spontaneous applause. The next day, the wire news organization Agence France-Presse gushed in a widely disseminated article that Atala had printed a "real kidney" on a machine that "eliminates the need for donors when it comes to organ transplants."

The future was coming.

And then it wasn't.

In fact, what Atala had held on stage wasn't a working human kidney. It was inert, an extremely detailed model, a taste of what he hoped and thought bioprinting would one day bring. If you watched the presentation carefully, you could see that Atala never promised that what he held was a working organ. Still, critics pounced on what they viewed as a high-grade exercise in special effects.



"Tech is going to have to improve a great deal before we're able to bioprint a kidney or a heart . . . and keep it alive."

Last year, Jennifer Lewis, a materials scientist at Harvard and a leading researcher in bioprinting (her specialty is engineering vascularized tissues) seemed to criticize Atala in an interview with the *New Yorker*. "I thought it was misleading," she said, referring to the TED Talk. "We don't want to give people false expectations, and it gives the field a bad name."

In the aftermath of the TED Talk, Wake Forest issued a press release stressing that it would be a long time before a bioprinted kidney could come to market. When I asked Atala whether he'd learned anything from the controversy, he declined to comment on it directly, pointing instead to why he dislikes putting a time stamp on any particular project. "We do not want to give patients false hope," he told me.

The dust-up was neatly illustrative of one of the central challenges faced by researchers throughout the field of regenerative medicine: You want to stoke enthusiasm about what's possible, because enthusiasm can translate to press, funding and resources. You want to inspire the people around you and the next generation of scientists. But you don't want to misrepresent what's realistically within reach.

And when it comes to big, complicated organs, the field still has a way to go. Sit down with a pencil and a piece of paper and you could hardly dream

Get a closer look at the creations in Atala's laboratory at Smithsonian.com/organs

TEXAS HEART INSTITUTE

up something more architecturally or functionally complex than the human kidney. The interior of the fist-size organ is made up of solid tissues traversed by an intricate highway system of blood vessels, which measure as little as 0.010 millimeters in diameter, and approximately a million tiny filters known as nephrons, which send healthful fluids back into the bloodstream and waste down to the bladder in the form of urine. To bioprint a kidney, you'd have to be able to cultivate and introduce not only functioning kidney cells and nephrons, you'd also need to have mastered how to populate the organ with a vasculature to keep the organ fed with the blood and nutrients it needs. And you'd have to build it all from the inside out.

A "ghost" pig heart (left) stripped of its tissue cells. Some researchers hope to transplant such organs into people after seeding them with human cells.

Which is why many researchers are exploring options that don't include printing those structures from scratch but instead try to use those already designed by nature. At the Texas Heart Institute, in Houston, Doris Taylor, the director of the institute's regenerative medicine research program, is experimenting with decellularized pig hearts—organs that have been stripped of muscle and all other living tissue cells in a chemical bath, leaving only the underlying collagen matrix. A decellularized organ is pale and ghostly—it resembles a glow stick drained of the solution that once made it glow. But crucially, the process leaves the interior architecture of the organ intact, vasculature and all.

Taylor hopes one day to use decellularized pig hearts, repopulated with human cells, for transplant in human patients. So far, her team has injected the hearts with live bovine cells and inserted them into cows, where they successfully beat and pumped blood alongside the cows' original, healthy heart. For Taylor, this approach skirts the challenges of finding ways to print at the incredibly fine CONTINUED ON PAGE 94

EVAN KAFKA

THE SKELETON CREW

SCIENTISTS ARE USING **CUTTING-EDGE TECHNOLOGY** TO GROW HUMAN BONES IN THE LAB

"Grow your own bone" might not sound like much of a business slogan, since even children do just that naturally. But EpiBone, a two-year-old company based in Harlem, New York, has adopted the slogan because it sees a big opportunity: Surgeons perform about a million bone grafts in the United States each year, either with the patient's own bone tissue, necessitating two surgeries, or with synthetic or donated material, which a patient's body sometimes rejects.

"People are living much, much longer and technology is getting much, much better," says CEO Nina Tandon, who co-founded EpiBone. "And yet we're still relying on implants made out of titanium. We're still relying on painful double surgeries. We need to move things forward."

Here's how Tandon, a 35-year-old biomedical and electrical engineer, sees it working: A doctor uses a CT scanner to image the damaged section of bone and takes a small sample of fatty tissue. The scans and the sample are sent to EpiBone, which extracts stem cells—undifferentiated cells that can essentially be programmed to perform a wide array of functions. The cells are applied to a custom-cut scaffold of bovine bone that has been scrubbed of its living cells. EpiBone then places the construct into a specially designed bioreactor, about the size of a can of soda (each bone gets its own), with a "chamber" cast in the shape of a 3-D-printed bone model to ensure that the company's proprietary growth "cocktail" passing through the chamber seeds the bone tissue uniformly. What emerges, a few weeks later, is a replacement part that not only fits the patient's bone exactly but is made out of the patient's own cells.



Nina Tandon of EpiBone plans to begin human trials in three years.

In the future, Tandon says, EpiBone's technology could be used to treat anything from bone loss and broken femurs to complex facial fractures and genetic defects.

In March, EpiBone began a study that implanted newly grown cheekbones into 16 pigs at the Louisiana State University School of Veterinary Medicine. Tandon cautions that it will be some time before EpiBone, which has only three full-time employees now, is ready to move on to human beings. Still, early tests on bits of incubated bone have been encouraging, and plenty of venture capital has already poured in. "I think the science is ready, and just as important, the market is ready," Tandon says. "People understand how much potential there is in engineering these kinds of living parts." **–MATTHEW SHAER**



MIND MELD

BRAIN-TO-BRAIN COMMUNICATION IS NO LONGER UNTHINKABLE, OPENING UP A STARTLING WORLD OF NEW THERAPIES—AND DILEMMAS

BY Jerry Adler

ILLUSTRATION BY JOHN HERSEY

Telepathy, circa 23rd century: The Vulcan mind meld, accomplished by touching the temples with the fingertips, is an accepted technique for advancing the plot of a "Star Trek" episode with a minimum of dialogue, by sharing sensory impressions, memories and thoughts between nonhuman characters.

Telepathy, 2015: At the Center for Sensorimotor Neural Engineering of the University of Washington, a young woman dons an electroencephalogram cap, studded with electrodes that can read the minute fluctuations of voltage across her brain. She is playing a game, answering questions by turning her gaze to one of two strobe lights labeled "yes" and "no." The "yes" light is flashing at 13 times a second, the "no" at 12, and the difference is too small for her to perceive, but sufficient for a computer to detect in the firing of neurons in her visual cortex. If the computer determines she is looking at the "yes" light, it sends a signal to a room in another building, where another woman is sitting with a magnetic coil positioned behind her head. A "yes" signal activates the magnet, causing a brief disturbance in the second

subject's visual field, a virtual flash (a "phosphene") that she describes as akin to the appearance of heat lightning on the horizon. In this way, the first woman's answers are conveyed to another person across the campus, going "Star Trek" one better: exchanging information between two minds that aren't even in the same place.

For nearly all of human history, only the five natural senses were known to serve as a way into the brain, and language and gesture as the channels out. Now researchers are breaching those boundaries of the mind, moving information in and out and across space and time, manipulating it and potentially enhancing it. This experiment and others have been a "demonstration to get the conversation started," says researcher Rajesh Rao, who conducted it along with his colleague Andrea Stocco. The conversation, which will likely dominate neuroscience for much of this century, holds the promise of new technology that will dramatically affect how we treat dementia, stroke and spinal cord injuries. But it will also be about the ethics of powerful new tools to enhance thinking, and, ultimately, the very nature of consciousness and identity.

That new study grew out of Rao's work in "brain-computer interfaces," which process neural impulses into signals that can control external devices. Using an EEG to control a robot that can navigate a room and pick up objects—which Rao and his colleagues demonstrated as far back as 2008—may be commonplace someday for quadriplegics.

In what Rao says was the first instance of a message sent directly from one human brain to another, he enlisted Stocco to help play a basic "Space Invaders"-type game. As one person watched the attack on a screen and communicated by using only thought the best moment to fire, the other got a magnetic impulse that caused his hand, without conscious effort, to press a button on a keyboard. After some practice, Rao says, they got quite good at it.

"That's nice," I said, when he described the procedure to me. "Can you get him to play the piano?"

Rao sighed. "Not with anything we're using now."

For all that science has studied and mapped the brain in recent decades, the mind remains a black box. A famous 1974 essay by the philosopher Thomas Nagel asked, "What Is It Like to Be a Bat?" and concluded that we will never know; another consciousness—another person's, let alone a member of another species—can never be comprehended or accessed. For Rao and a few others to open that door a tiny crack, then, is a notable achievement, even if the work has mostly underscored how big a challenge it is, both conceptually and technologically.

The computing power and the programming are up to the challenge; the problem is the interface between brain and computer, and especially the one that goes in the direction from computer to brain. How do you deliver a signal to the right group of nerve cells among the estimated 86 billion in a human brain? The most efficient approach is an implanted transceiver that can be hard-wired to stimulate small regions of the brain, even down to a single neuron. Such devices are already in use for "deep brain stimulation," a technique for treating patients with Parkinson's and other disorders with electrical impulses. But it's one thing to perform brain surgery for an incurable disease, and something else to do it as part of an experiment whose benefits are speculative at best.



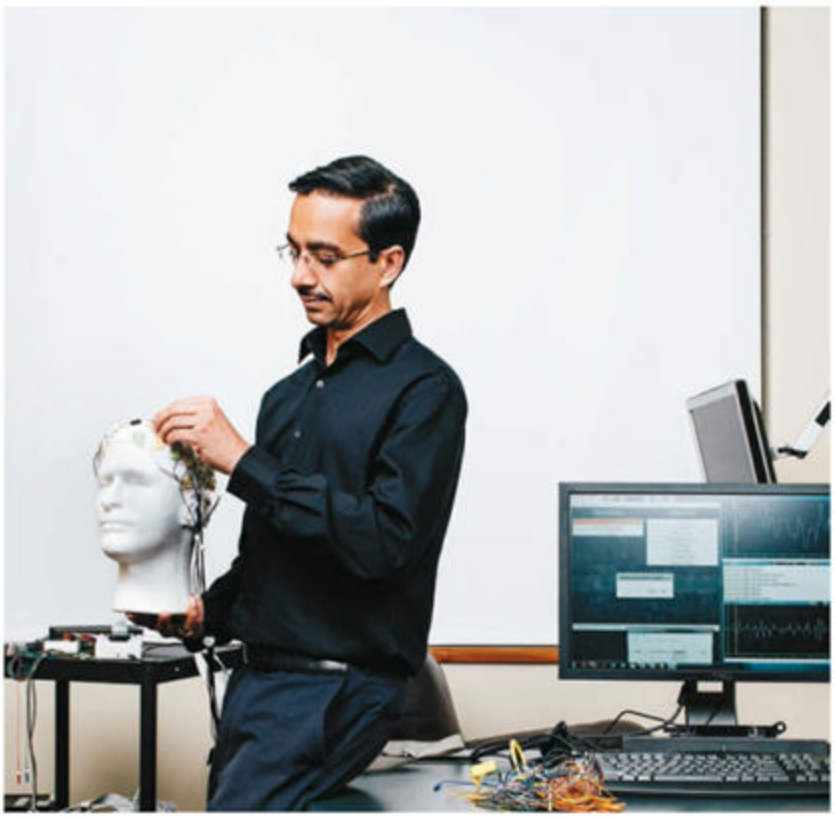
To monitor the brain noninvasively, Rajesh Rao fits study participants with EEG caps and adds conductive gel so the scalp and electrodes make good contact.

JOSE MANDOJANA (2)

So Rao used a technique that does not involve opening the skull, a fluctuating magnetic field to induce a tiny electric current in a region of the brain. It appears to be safe—his first volunteer was his collaborator, Stocco—but it is a crude mechanism. The smallest area that can be stimulated in this way, Rao says, is not quite half an inch across. This limits its application to gross motor movements, such as hitting a button, or simple yes-or-no communication.

Another way to transmit information, called focused ultrasound, appears to be capable of stimulating a region of the brain as small as a grain of rice. While the medical applications for ultrasound, such as imaging and tissue ablation, use high frequencies, from 800 kilohertz up to the megahertz





Researchers are breaching the boundaries of the mind, moving information in and out and across space and time.

range, a team led by Harvard radiologist Seung-Schik Yoo found that a frequency of 350 kilohertz works well, and apparently safely, to send a signal to the brain of a rat. The signal originated with a human volunteer outfitted with an EEG, which sampled his brainwaves; when he focused on a specific pattern of lights on a computer screen, a computer sent an ultrasound signal to the rat, which moved his tail in response. Yoo says the rat showed no ill effects, but the safety of focused ultrasound on the human brain is unproven. Part of the problem is that, unlike magnetic stimulation, the mechanism by which ultrasound waves—a form of mechanical energy—creates an electric potential isn't fully understood. One possibility is that it operates indirectly by "popping" open the vesicles, or sacs, within the cells of the brain, flooding them with neurotransmitters, like delivering a shot of dopamine to exactly the right area. Alternatively, the ultrasound could induce cavitation—bubbling—in the cell membrane, changing its electrical properties. Yoo suspects that the brain contains receptors for mechanical stimulation, including ultrasound, which have been largely overlooked by neuroscientists. Such receptors would account for the phenomenon of "seeing stars," or flashes of light, from a blow to the head, for instance. If focused ultrasound is proven safe, and becomes a feasible approach to a computer-brain interface, it would open up a wide range of unexplored—in fact, barely imagined—possibilities.

Direct verbal communication between individuals—a more sophisticated version of Rao's experiment, with two connected people exchanging explicit statements just by thinking them—is the most obvious application, but it's not clear that a species possessing language needs a more technologically advanced way to say "I'm running late," or even "I love you." John Trimper, an Emory University doctoral candidate in psychology, who has written about the ethical implications of brain-to-brain interfaces, speculates that the technology, "especially through wireless transmissions, could eventually allow soldiers or police—or criminals—

STROKES OF GENIUS

NOT IMPOSSIBLE LABS HAS DEVELOPED A BREAKTHROUGH APPROACH TO COMMUNICATION—**WRITING WITH YOUR BRAIN**

The notion of a nefarious power somehow dictating what individuals say and do by tampering with their brains is, for the moment at least, still fictional. But there's a less diabolical kind of mind control and it's very real, as Mick Ebeling is happy to show you.

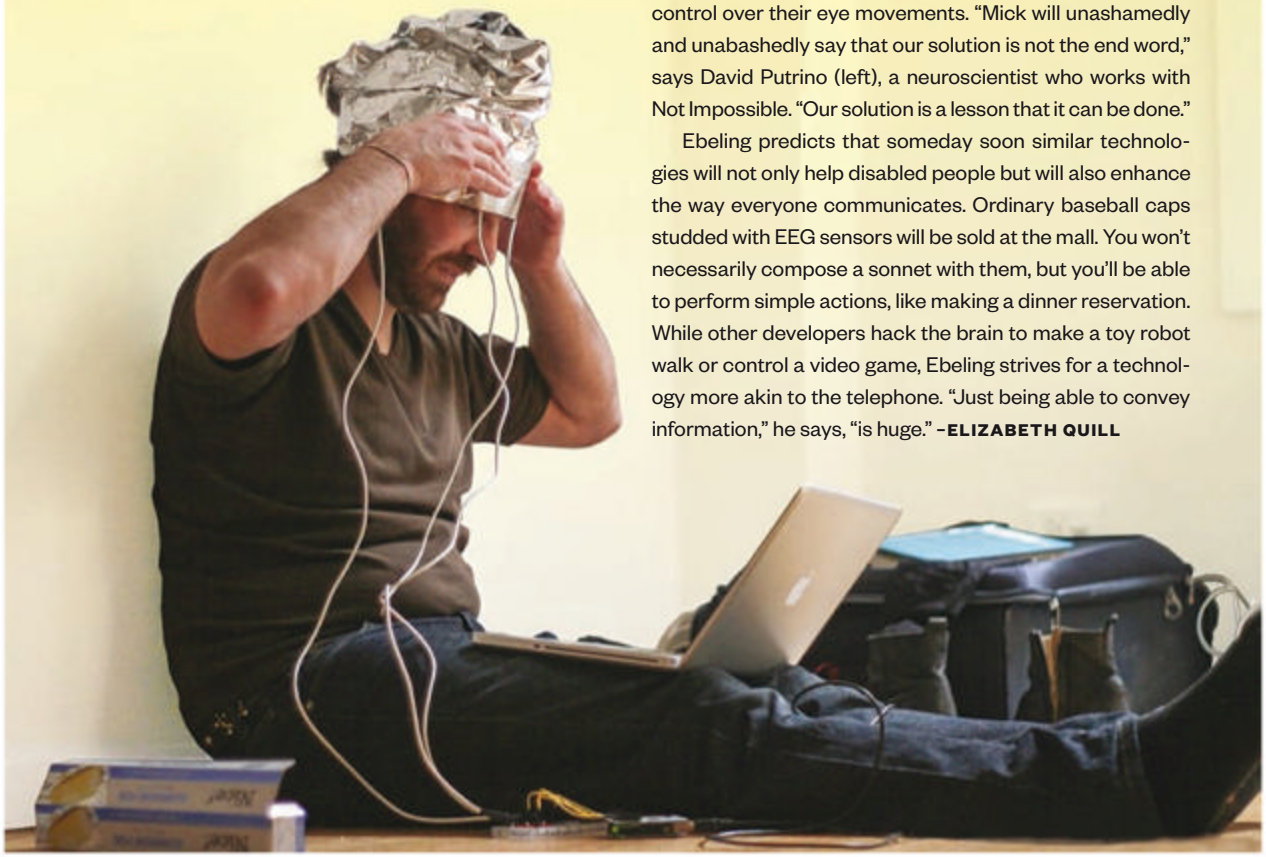
In his Venice, California, laboratory he is developing a device that will permit disabled people to write with their minds—no pencil strokes or keystrokes required. Called the Brainwriter, it combines new, low-cost headsets that monitor the brain's electrical activity with eye-tracking technology and open-source software. By thinking about a single idea or word, a person can command a computer cursor to enter writing mode, the equivalent of putting pen to paper. Then, as the eyes move, the cursor traces their path on-screen.

"I like to see things that are not supposed to be done, be done," says Ebeling, co-founder of the hopeful-sounding company Not Impossible. He's not an engineer himself—he's a film and TV producer—so he recruits technical experts to help him solve real-world problems. "Help one, help many" is one of his mantras. For instance, Ebeling and his team 3-D-printed prosthetic arms for amputees in South Sudan, starting with a teenage boy named Daniel.

Brainwriter was inspired by an L.A. graffiti artist named Tony Quan (tag name Tempt One), who is afflicted by amyotrophic lateral sclerosis and no longer has control over his muscles. At first, Ebeling and his crew fashioned a device out of plastic eyeglasses, a coat hanger and a hacked-open PlayStation 3 camera. "Steve Jobs would roll over in his grave if he saw our stuff," Ebeling says. In this version, Quan blinked to enter writing mode and select his drawing tools. But as his condition worsened, he could no longer control the device with his blinks.

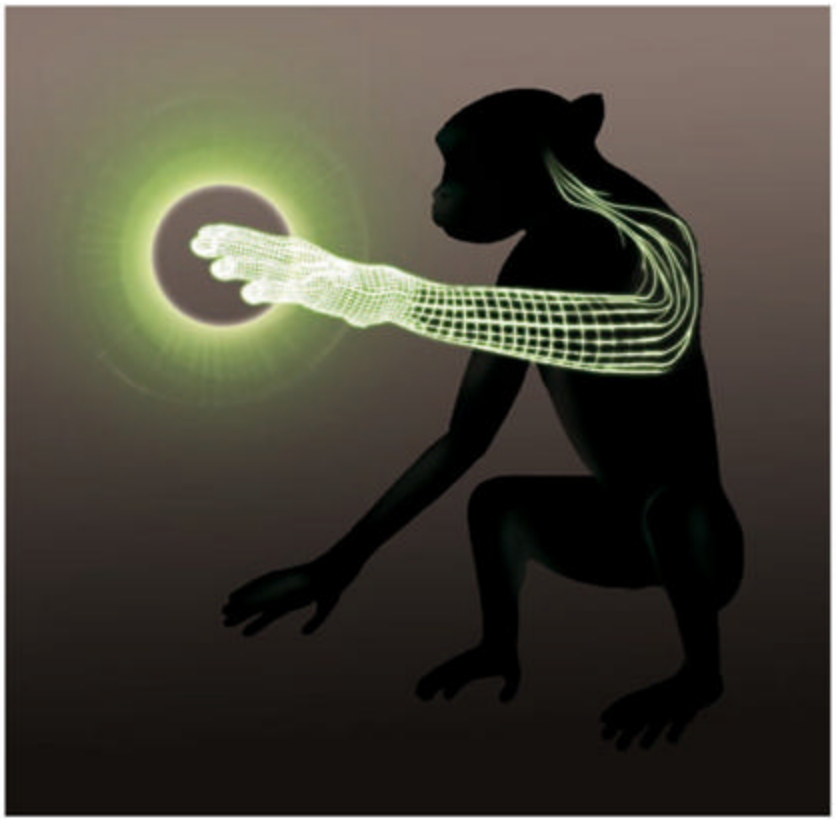
So the next step was to tap into brain waves, monitored via electroencephalogram. A focusing brain produces a particular EEG pattern, which the computer software recognizes and processes the same way it processes the click of a mouse. Still in the testing phase, Brainwriter will give patients with paralysis a new way to communicate, more efficient than the current method of spelling out words letter by letter. In later iterations, it might be adapted for people with no control over their eye movements. "Mick will unashamedly and unabashedly say that our solution is not the end word," says David Putrino (left), a neuroscientist who works with Not Impossible. "Our solution is a lesson that it can be done."

Ebeling predicts that someday soon similar technologies will not only help disabled people but will also enhance the way everyone communicates. Ordinary baseball caps studded with EEG sensors will be sold at the mall. You won't necessarily compose a sonnet with them, but you'll be able to perform simple actions, like making a dinner reservation. While other developers hack the brain to make a toy robot walk or control a video game, Ebeling strives for a technology more akin to the telephone. "Just being able to convey information," he says, "is huge." **–ELIZABETH QUILL**



NOT IMPOSSIBLE LABS

to communicate silently and covertly during operations." That would be in the distant future. So far, the most content-rich message sent brain-to-brain between humans traveled from a subject in India to one in Strasbourg, France. The first message, laboriously encoded and decoded into binary symbols by a Barcelona-based group, was "*hola*." With a more sophisticated interface one can imagine, say, a paralyzed stroke victim communicating to a caregiver—or his dog. Still, if what he's saying is, "Bring me the newspaper," there are, or will be soon, speech synthesizers—and robots—that can do that. But what if the person is Stephen Hawking, the great physicist afflicted by ALS, who communicates by using a cheek muscle to type the first letters of a word? The world could surely benefit from a direct channel to *his* mind.



Monkeys in a recent study used their brains to control a virtual arm and manipulate virtual objects. Electrical signals fed back to the brain mimicked the sense of touch.

NICOLELIS LAB

Maybe we're still thinking too small. Maybe an analog to natural language isn't the killer app for a brain-to-brain interface. Instead, it must be something more global, more ambitious—information, skills, even raw sensory input. What if medical students could download a technique directly from the brain of the world's best surgeon, or if musicians could directly access the memory of a great pianist? "Is there only one way of learning a skill?" Rao muses. "Can there be a shortcut, and is that cheating?" It doesn't even have to involve another human brain on the other end. It could be an animal—what would it be like to experience the world through smell, like a dog—or by echolocation, like a bat? Or it could be a search engine. "It's cheating on an exam if you use your smartphone to look things up on the Internet," Rao says, "but what if you're already connected to the Internet through your brain? Increasingly the measure of success in society is how quickly we access, digest and use the information that's out there, not how much you can cram into your own memory. Now we do it with our fingers. But is there anything inherently wrong about doing it just by thinking?"

What if medical students could download a technique directly from the brain of the world's best surgeon?

Or, it could be your own brain, uploaded at some providential moment and digitally preserved for future access. "Let's say years later you have a stroke," says Stocco, whose own mother had a stroke in her 50s and never walked again. "Now, you go to rehab and it's like learning to walk all over again. Suppose you could just download that ability into your brain. It wouldn't work perfectly, most likely, but it would be a big head start on regaining that ability."

Miguel Nicolelis, a creative Duke neuroscientist and a mesmerizing lecturer on the TED Talks circuit, knows the value of a good demonstration. For the 2014 World Cup, Nicolelis—a Brazilian-born soccer aficionado—worked with others to build a robotic exoskeleton controlled by EEG impulses, enabling a young paraplegic man to deliver the ceremonial first kick. Much of his work now is on brain-to-brain communication, especially in the highly esoteric techniques of linking minds to work together on a problem. The minds aren't human ones, so he can use electrode implants, with all the advantages that conveys.

One of his most striking experiments involved a pair of lab rats, learning together and moving in synchrony as they communicated via brain signals. The rats were trained in an enclosure with two levers and a light above each. The left- or right-hand light would flash, and the rats learned to press the corresponding lever to receive a reward. Then they were separated, and each fitted with electrodes to the motor cortex, connected via computers that sampled brain impulses from one rat (the "en-

coder"), and sent a signal to a second (the "decoder"). The "encoder" rat would see one light flash—say, the left one—and push the left-hand lever for his reward; in the other box, both lights would flash, so the "decoder" wouldn't know which lever to push—but on receiving a signal from the first rat, he would go to the left as well.



Robotic skeletons with tactile sensors, held here by Miguel Nicolelis, detect changes in position, temperature and pressure and send that information to the brain.

Nicolelis added a clever twist to this demonstration. When the decoder rat made the correct choice, he was rewarded, and the encoder got a second reward as well. This served to reinforce and strengthen the (unconscious) neural processes that were being sampled in his brain. As a result, both rats became more accurate and faster in their responses—"a pair of interconnected brains . . . transferring information and collaborating in real time."

In another study, he wired up three monkeys to control a virtual arm; each could move it in one dimension, and as they watched a screen they learned to work together to manipulate it to the correct location. He says he can imagine using this technology to help a stroke victim regain certain abilities by networking his brain with that of a healthy volunteer, gradually adjusting the proportions of input until the patient's brain is doing all the work. And he believes this principle could be extended indefinitely, to enlist millions of brains to work together in a "biological computer" that tackled questions that could not be posed, or answered, in binary form. You could ask this network of brains for the meaning of life—you might not get a good answer, but unlike a digital computer, "it" would at least understand the question. At the same time, Nicolelis criticizes efforts to emulate the mind in a digital computer, no matter how powerful, saying they're "bogus, and a waste of billions of dollars." The brain works by different principles, modeling the world by analogy. To convey this, he proposes a new concept he calls "Gödelian information," after the mathematician Kurt Gödel; it's an analog representation of reality that cannot be reduced to bytes, and can never be captured by a map

PAULO WHITAKER / REUTERS / CORBIS

UPLOAD YOUR MIND

THE IDEA IS ABOUT AS SCIENCE FICTION AS IT GETS. BUT **SURPRISING PROGRESS** IN NEUROSCIENCE HAS SOME ENTREPRENEURS READY TO PRESS "SEND"

In London, Benjamin Franklin once opened a bottle of for-tified wine from Virginia and poured out, along with the refreshment, three drowned flies, two of which revived after a few hours and flew away. Ever the visionary, he wondered about the possibility of incarcerating himself in a wine barrel for future resurrection, "to see and observe the state of America a hundred years hence." Alas, he wrote to a friend in 1773, "we live in an age too early . . . to see such an art brought in our time to its perfection."

If Franklin were alive today he would find a kindred spirit in Ken Hayworth, a neuroscientist who also wants to be around in 100 years but recognizes that, at 43, he's not likely to make it on his own. Nor does he expect to get there preserved in alcohol or a freezer; despite the claims made by advocates of cryonics, he says, the ability to revivify a frozen body "isn't really on the horizon." So Hayworth is hoping for what he considers the next best thing. He wishes to upload his mind—his memories, skills and personality—to a computer that can be programmed to emulate the processes of his brain, making him, or a simulacrum, effectively immortal (as long as someone keeps the power on).

Hayworth's dream, which he is pursuing as president of the Brain Preservation Foundation, is one version of the "technological singularity." It envisions a future of "substrate-independent minds," in which human and machine consciousness will merge, transcending biological limits of time, space and memory. "This new substrate won't be dependent on an oxygen atmosphere," says Randal Koene, who works on the same problem at his organization, Carboncopies.org. "It can go on a journey of 1,000 years, it can process more information at a higher speed, it can see in the X-ray spectrum if we build it that way." Whether Hayworth or Koene will live to see this is an open question. Their most optimistic scenarios call for at least 50 years, and uncounted billions of dollars, to implement their goal. Meanwhile, Hayworth hopes to achieve the ability to preserve an entire human brain at death—through chemicals, cryonics or both—to keep the structure intact with enough detail that it can, at some future time, be scanned into a database and emulated on a computer.

That approach presumes, of course, that all of the subtleties of a human mind and memory are contained in its anatomical

of the connections between neurons ("Upload Your Mind," see below). "A computer doesn't generate knowledge, doesn't perform introspection," he says. "The content of a rat, monkey or human brain is much richer than we could ever simulate by binary processes."

The cutting edge of this research involves actual brain prostheses. At the University of Southern California, Theodore Berger is developing a microchip-based prosthesis for the hippocampus, the part of the mammalian brain that processes short-term impressions into long-term memories. He taps into the neurons on the input side, runs the signal through a program that mimics the transformations the hippocampus normally performs, and sends it back into the brain. Others have used Berger's technique to send the memory of a learned behavior from one rat to another; the second rat then learned the task in much less time than usual. To be sure, this work has only been done in rats, but because degeneration of the hippocampus is one of the hallmarks of dementia in human beings, the potential of this research is said to be enormous.

Given the sweeping claims for the future potential of brain-to-brain communication, it's useful to list some of the things that are not being claimed. There is, first, no implication that humans possess any form of natural (or supernatural) telepathy; the voltages flickering inside your skull just aren't strong enough to be read by another brain without electronic enhancement. Nor can signals (with any technology we possess, or envision) be transmitted or received surreptitiously, or at a distance. The workings of your mind are secure, unless you give someone else the key by submitting to an implant or an EEG. It is, however, not too soon to start considering the ethical implications of future developments, such as the ability to implant thoughts in other people or control their behavior (prisoners, for example) using devices designed for those purposes. "The technology is outpacing the ethical discourse at this time," Emory's Trimper says, "and that's where things get dicey." Consider that much of the brain traffic in these experiments—and certainly anything like Nicolelis' vision of hundreds or thousands of brains working together—involves communicating over the Internet. If you're worried now about someone hacking your credit card information, how would you feel about sending the contents of your mind into the cloud?

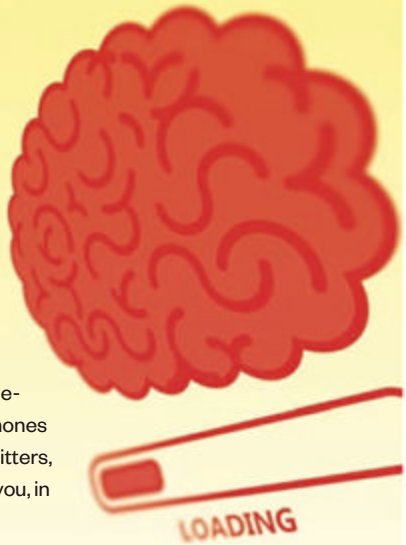
There's another track, though, on which brain-to-brain communication is being studied. Uri Hasson, a Princeton neuroscientist, uses functional magnetic resonance imaging to research how one brain influences another, how they are coupled in an intricate dance of cues and feedback loops. He is focusing on a communication technique that he considers far superior to EEGs used with transcranial magnetic stimulation, is noninvasive and safe and requires no Internet connection. It is, of course, language.

BEATRIZ GASCON J / SHUTTERSTOCK

structure—conventional wisdom among neuroscientists, but it's still a hypothesis. There are electrochemical processes at work. Are they captured by a static map of cells and synapses? We won't know, advocates argue, until we try to do it.

The initiatives require a big bet on the future of technology. A 3-D map of all the cells and synapses in a nervous system is called a "connectome," and so far researchers have produced exactly one, for a roundworm called *Caenorhabditis elegans*, with 302 neurons and about 7,000 connections among them. A human brain, according to one reasonable estimate, has about 86 billion neurons and 100 trillion synapses. And then there's the electrochemical activity on top of that. In 2013, announcing a federal initiative to produce a complete model of the human brain, Francis Collins, head of the National Institutes of Health, said it could generate "yottabytes" of data—a million million million megabytes. To scan an entire human brain at the scale Hayworth thinks is necessary—effectively slicing it into virtual cubes ten nanometers on a side—would require, with today's technology, "a million electron microscopes running in parallel for ten years." Mainstream researchers are divided between those who regard Hayworth's quest as impossible in practice, and those, like Miguel Nicolelis of Duke University, who consider it impossible in theory. "The brain," he says, "is not computable."

And what does it mean for a mind to exist outside a brain? One immediately thinks of the disembodied HAL in *2001: A Space Odyssey*. But Koene sees no reason that, if computers continue to grow smaller and more powerful, an uploaded mind couldn't have a body—a virtual one, or a robotic one. Will it sleep? Experience hunger, pain, desire? In the absence of hormones and chemical neurotransmitters, will it feel emotion? It will be you, in a sense, but will you be it?



These questions don't trouble Hayworth. To him, the brain is the most sophisticated computer on earth, but only that, and he figures his mind could also live in one made of transistors instead. He hopes to become the first human being to live entirely in cyberspace, to send his virtual self into the far future—a journey as fantastic as that of those two flies that fell into a wine bottle in America and came back to life in England. **–J.A.**

LEVITATION NATION

BACK TO THE FUTURE *MADE THE HOVERBOARD COOL. GREG AND JILL HENDERSON MADE IT POSSIBLE*

BY Chris Colin



On a recent Wednesday afternoon, a guy in blue jeans and a T-shirt drifted back and forth across a gently sloping half-pipe in an office park southwest of San Jose. Instead of skating, though, he was hovering: a real-world Marty McFly, the time-traveling teen who glided on air around Hill Valley in *Back to the Future Part II*.

The Hendo hoverboard, invented by Greg Henderson and launched with the help of his wife, Jill, nearly broke the Internet when it appeared in a Kickstarter video last year featuring company engineer and resident stuntman Garrett Foshay. A subsequent video starring skateboarding legend Tony Hawk confirmed that the board was real. "That was my first 1080!" Hawk joked, completing almost three spins before tumbling off.

For the millions enthralled by the image of Michael J. Fox as Marty McFly hoverboarding in that far-off time of, yes, 2015, the Hendo fulfills a long-held desire. Compared with the rigmarole of flying—the fuss, the expense, the actual airplane—hovering is a magical little operation: a single rider breaking free from the planet's pull. It's "deeply embedded in the public imagination," says Bob Gale, a writer and producer of the *Back to the Future* trilogy.

It was something more serious that inspired Greg and Jill, both California natives: San Francisco's 1989 Loma Prieta earthquake. News images of collapsed homes and pancaked freeways stuck with Greg, a young Army lieutenant stationed in Georgia at the time. After leaving the Army and becoming an architect, he began thinking about a new way to protect cities and save lives: levitating buildings.

With little technical experience but a knack for Internet research, Greg built a prototype. The current model features four "hover engines" with magnets coordinating to generate a concentrated field, which then generates an opposing field in a conductive material below, in the floor. When the two fields repel—lift. (Of course, it's not simple; tech whizzes at Google X reportedly abandoned their hover research.)

"We made the hoverboard because it's the perfect way to illustrate our 'magnetic field architecture' technology," Jill said when I met her at the offices of Arx Pax, the company founded to advance their technology. In theory, a building alerted to a coming quake could automatically activate the system; support structures would fall away and the building would float above the trembling ground.

"Give us 30 years, and we'll hover a skyscraper," Greg promised. "Or imagine converting HOV lanes into hover lanes. The potential is limitless."

For now there are challenges. The hoverboard is wobbly and dependent on a copper substrate beneath it, and riders have to be content with about 10 minutes of power. But the Hendersons' story is, in the end, about getting an invention off the ground. And they predict that a commercial version of the Hendo will come on the market in the next few years.

After finishing his latest demo, Foshay powers down the board and steps off. He's logged many hours at the half-pipe, but the thrill hasn't worn off: After all, as he says, "I'm the best hoverboard rider in the world right now."

PHOTOGRAPH BY **TIMOTHY ARCHIBALD**



Garrett Foshay rides the Hendo, which hovers about an inch off the ground.

THE SHELTERING SKY

HUNDREDS OF MILES ABOVE EARTH, ORBITING SATELLITES ARE BECOMING A **BOLD NEW WEAPON** IN THE AGE-OLD FIGHT AGAINST FAMINE

BY Ariel Sabar

PHOTOGRAPHS BY **ZACHARIAS ABUBEKER**





In early October, after the main rainy season, Ethiopia's central Rift Valley is a study in green. Fields of wheat and barley lie like shimmering quilts over the highland ridges. Across the valley floor below, beneath low-flying clouds, farmers wade through fields of African cereal, plucking weeds and primping the land for harvest.

It is hard to look at such lushness and equate Ethiopia with famine. The f-word, as some people call it, as though the mere mention were a curse, has haunted the country since hundreds of thousands of Ethiopians died three decades ago in the crisis that inspired Live Aid, "We Are the World" and other spectacles of Western charity. The word was on no one's lips this year. Almost as soon as I'd landed in Addis Ababa, people told me that 2014 had been a relatively good year for Ethiopia's 70 million subsistence farmers.

But Gabriel Senay wasn't so sure. A scientist with the U.S. Geological Survey, he'd designed a system that uses NASA satellites to detect unusual spikes in land temperature. These anomalies can signal crop failure, and Senay's algorithms were now plotting these hot zones along a strip of the Rift Valley normally thought of as a breadbasket. Was something amiss? Something aid workers hadn't noticed?

Senay had come to Ethiopia to find out—to "ground-truth" his years of painstaking research. At the top of a long list of people eager for results were officials at the U.S. Agency for International Development, who had made a substantial investment in his work. The United States is the largest donor of food aid to the world, splitting $1.5 billion to $2.5 billion a year among some 60 countries in Africa, Asia and Latin America. Ethiopia usually gets the biggest slice, but it's a large pie, and to make sure aid gets to the neediest, USAID spends $25 million a year on scientific forecasts of where hunger will strike next.

Senay's innovations, some officials felt, had the potential to take those forecasts to a new level, by spotting the faintest first footsteps of famine almost anywhere in the world. And the earlier officials heard those footsteps, the faster they would be able to mobilize forces against one of humanity's oldest and cruelest scourges.

In the paved and wired developed world, it's hard to imagine a food emergency staying secret for long. But in countries with bad roads, spotty phone service and shaky political regimes, isolated food shortfalls can metastasize into full-blown humanitarian crises before the world notices. That was in many ways the case in Ethiopia in 1984, when the failure of rains in the northern highlands was aggravated by a guerrilla war



"My grandparents' world was 20 kilometers," says Gabriel Senay (at the U.S. Earth Resources Observation and Science Center), who uses satellite data to assess croplands in places such as Ethiopia, where he grew up.

GREG LATZA

along what is now the Eritrean border.

Senay, who grew up in Ethiopian farm country, the youngest of 11 children, was then an undergraduate at the country's leading agricultural college. But the famine had felt remote even to him. The victims were hundreds of miles to the north, and there was little talk of it on campus. Students could eat injera—the sour pancake that is a staple of Ethiopian meals—just once a week, but Senay recalls no other hardships. His parents were similarly spared; the drought had somehow skipped over their rainy plateau.

That you could live in one part of a country and be oblivious to mass starvation in another: Senay would think about that a lot later.

The Great Rift Valley splits Ethiopia into nearly equal parts, running in a ragged diagonal from the wastelands of the Danakil Depression in the northeast to the crocodile haunts of Lake Turkana in the southwest. About midway along its length, a few hours' drive south of Addis, it bisects a verdant highland of cereal fields.

Senay, who is 49, sat in the front seat of our Land Cruiser, wearing a baseball cap lettered, in cursive, "Life is Good." Behind us were two other vehicles, shuttling half a dozen American and Ethiopian scientists excited enough by Senay's research to want to see its potential firsthand. We caravanned through the gritty city of Adama and over the Awash River, weaving through cavalcades of donkeys and sheep.

Up along the green slopes of the Arsi highlands, Senay looked over his strangely hued maps. The pages were stippled with red and orange dots, each a square kilometer, where satellites 438 miles overhead had sensed a kind of fever on the land.

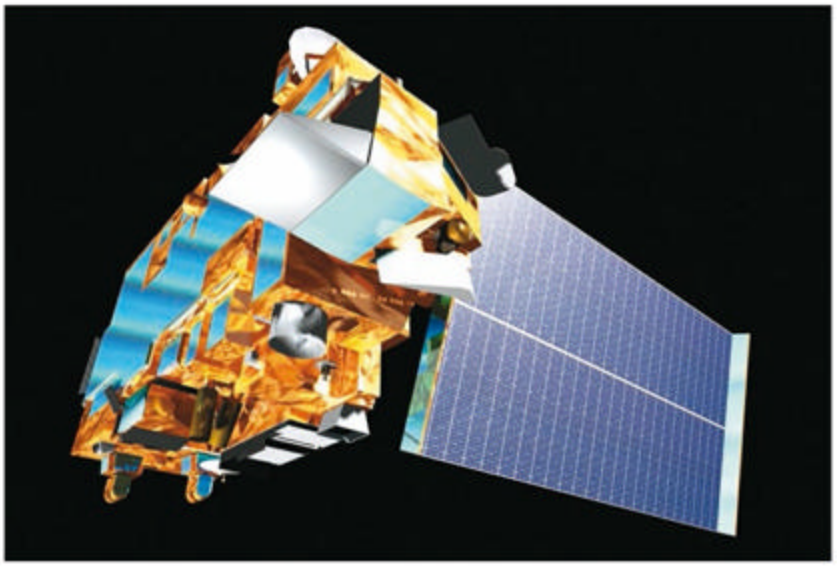
From the back seat, Curt Reynolds, a burly crop analyst with the U.S. Department of Agriculture in Washington, who advises USAID (and is not known to sugar-coat his opinions), asked whether recent rains had cooled those fevers, making some of Senay's assessments moot. "There are still pixels that are really hurting," Senay insisted.

We turned off the main road, jouncing along a muddy track to a local agricultural bureau. Huseen Muhammad Galatoo, a grave-looking man who was the bureau's lead agronomist, led us into a musty office. A faded poster on one wall said, "Coffee: Ethiopia's Gift to the World."

Galatoo told us that several Arsi districts were facing their worst year

in decades. A failure of the spring *belg* rains and a late start to the summer *kiremt* rains had left some 76,000 animals dead and 271,000 people—10 percent of the local population—in need of emergency food aid.

"Previously, the livestock used to survive somehow," Galatoo said, through an interpreter. "But now there is literally nothing on the ground."



NASA's flagship earth-observing satellite, Terra, orbits pole-to-pole 16 times a day, taking readings of the atmosphere, oceans, land, snow and ice.

Nomads searching for water, villagers battling malaria: When they look to the heavens for help, Senay wants satellites looking back.

In the face of such doleful news, Senay wasn't in the mood for self-congratulation. But the truth was, he'd nailed it. He'd shown that satellites could spot crop failure—and its effects on livestock and people—as never before, at unprecedented scale and sensitivity. "The [current] early warning system didn't fully capture this," Alemu Asfaw, an Ethiopian economist who helps USAID forecast food crises, said in the car afterwards, shaking his head. "There had been reports of erratic rainfall. But no one expected it to be that bad." No one, that is, but Senay, whose work, Reynolds said, could be "a game changer for us."

Satellites have come a long way since Russia's *Sputnik 1*—a beachball-size sphere with four chopstick-like radio antennas—entered orbit, and history, in 1957. Today, some 1,200 artificial satellites orbit Earth. Most are still in traditional lines of work: bouncing phone calls and television signals across the globe, beaming GPS coordinates, monitoring weather, spying. A smaller number watch over the planet's wide-angle afflictions, like deforestation, melting glaciers and urban sprawl. But only recently have scientists sicced satellites on harder-to-detect, but no less perilous threats to people's basic needs and rights.

Senay is on the leading edge of this effort, focusing on hunger and disease—ills whose solutions once seemed resolutely earthbound. Nomads searching for water, villagers battling malaria, farmers aching for rain: When they look to the heavens for help, Senay wants satellites looking back.

He was born in the northwest Ethiopian town of Dangila, in a house without electricity or plumbing. To cross the local river with his family's 30 cattle, little Gabriel clung to the tail of an ox, which towed him to the grazing lands on the other side. High marks in school—and a father who demanded achievement, who called Gabriel "doctor" while the boy was still in diapers—propelled him to Ethiopia's Haramaya University and then to the West, for graduate studies in hydrology and agricultural engineering.

Not long after earning a PhD at Ohio State University, he landed a job that felt more like a mission—turning American satellites into defenders of Africa's downtrodden. His office, in the South Dakota countryside 18 miles northeast of Sioux Falls, is home to the Earth Resources Observation and Science Center, a low building, ringed by rows of tinted windows, looking a bit like a spaceship that emergency-landed in some hapless farmer's corn and soybean spread. Run by the U.S. Geological Survey, it's where the planet gets a daily diagnostic exam. Giant antennas and parabolic dishes ingest thousands of satellite images a day, keeping an eye on the pulse of the planet's waters, the pigment of its land and the musculature of its mountains.

Senay was soon living the American dream, with a wife, two kids and minivan in a Midwestern suburb. But satellites were his bridge home, closing the distance between here and there, now and then. "I came to know more about Ethiopia in South Dakota when looking at it from satellites than I did growing up," he told me. As torrents of data flow through his calamity-spotting algorithms, he says, "I imagine the poor farmer in Ethiopia. I imagine a guy struggling to farm who never got a chance to get educated, and that kind of gives me energy and some bravery."

His goal from the outset was to turn satellites into high-tech divining rods, capable of finding water—and mapping its effects—across Africa. Among scientists who study water's whereabouts, Senay became a kind of rock star. Though nominally a bureaucrat in a remote outpost of a federal agency, he

NASA

AN EYE FOR TROUBLE

FOR GEORGE CLOONEY AND THE UNITED NATIONS, THE NEW FRONTIER IN SATELLITES IS **HUMANITARIAN AID**

They beam phone and TV signals around the globe. They peer into enemy territory. And since 1972, with the launch of the United States' Landsat 1, satellites have kept watch over the planet's natural resources, tracking deforestation and urban sprawl. But they've increasingly taken on an urgent new role as human rights watchdogs.

U.N. satellite whisperers watch the migrations of people displaced by war in Syria and Somalia to target aid to the right places at the right times. The team, known as UNOSAT, also used satellites to monitor the pace of Ebola treatment center construction in West Africa and to confirm that crowds of people—members of the Yazidi minority—were stranded on Iraq's Mount Sinjar amid attacks by the Islamic State.

"We are not *Enemy of the State* and James Bond speed yet," says Einar Bjorgo, the manager of UNOSAT, which is based in Geneva. "But when I say real time or near real time, I mean we can have our analysis out within six hours after the satellite flew over the area, no matter where on the planet."

The Satellite Sentinel Project, co-founded in 2010 by the actor George Clooney, scrutinizes Sudan and South Sudan from space, looking for evidence of atrocities and sounding alarms in social and conventional media. In 2011, satellites tipped Amnesty International to a sharp growth in political prisoner camps in North Korea, helping "provide irrefutable evidence of the existence, location, and scale" of the camps, "which the government can no longer deny," the group says.

Such advances stem, in part, from greatly improved photographic resolution. The first nonmilitary satellites, which struggled to tell a football field from a forest, have given way to models that can distinguish a sedan from a pickup. Another factor is coverage. From 2011 to 2013, the number of nonmilitary earth-observing satellites in orbit grew by 65 percent, from 92 to 152, according to the Satellite Industry Association. That's nearly four times the growth rate of all satellites, and it means that more corners of the planet are eyed more closely than ever before.

The size of these digital photo albums has soared along with the number of people who can gape at them. In 2008, a U.S. policy change made Landsat images free over the web; more than 20 million have been downloaded. And no longer are mainframe computers needed to handle whopping image files. Thanks to leaps in microchip processing speeds, you can thumb through space-borne images on your smartphone.

As tens of thousands of South Sudanese streamed into Ethiopia last year, UNOSAT identified for U.N. officials the most suitable places for refugee camps. "We'll provide them information on local conditions, what the ground looks like, where the roads are, where nearby towns are," says Lars Bromley, principal analyst at UNOSAT. "A lot of that information simply doesn't exist for the majority of the world—especially not these really rural, really remote areas, which suddenly have to absorb 50,000 people."

In Iraq, satellite experts identified the site of a massacre from a witness who remembered details of the landscape but little else. "In that case," Bromley says, "we were told something like, They were taken from a building here, driven a few minutes down a road, then got to something that looked like a garbage dump where the grass looked burned. We say, OK . . . where could this be?"

Andrew Woods, a professor of international law at the University of Kentucky, imagines a future in which satellites reduce war crimes. Focusing on where rebels are marauding in northern Uganda, for instance, the U.N. might drop leaflets that read, Warning: Satellites Are Monitoring This Area. "Like security cameras in a dark alley," Woods has said, such warnings "can send a clear and strong message to potential perpetrators that someone is watching." **–A.S.**



A 2014 UNOSAT analysis of an Ebola treatment facility in Guinea.

UNITAR / UNOSAT; PP. 60–61 ZACHARIAS ABUBEKER





Farm kids in the Arsi area of Ethiopia. With a population of 94 million predicted to double in two decades, the nation faces dangerous "food insecurity," officials say.

AMAZON WATCH

CAN HIGH-FLYING **MODERN TECHNOLOGY** PROTECT THE WORLD'S LEAST MODERN PEOPLE? A U.S. RESEARCHER MAKES THE CASE

Robert Walker is making innovative use of satellite imagery to assess the last remaining Amazon tribes that have limited or no contact with the outside world. Walker, a University of Missouri anthropologist who previously did field work in the Amazon, has analyzed 27 communities of "uncontacted" people in Brazil, and one each in Colombia and Peru. Poring over high-resolution images purchased from commercial satellite companies, he sizes up each village, measuring gardens and counting huts. His goal is to share data with governments and advocates so they can better protect villages from threats such as logging, mining, violent drug traffickers and encounters with outsiders who carry infectious diseases against which natives have no immunity. One village, Walker found, is only 19 miles from a newly built road.

"It's a noninvasive way of knowing what is going on on the ground," he said. "If people leave a village, or a village has been attacked, we want to know as soon as possible."

The Amazon holds the world's largest concentration of isolated communities, with 50 to 100. Some are so small they face another threat: a shortage of healthy mating partners. In research published in the journal *Royal Society Open Science*, Walker identified three villages that "face an imminent threat of falling below a minimum viable population." Those villages consist of no more than nine huts on nine acres of cleared land.



A 2013 satellite view of a settlement of uncontacted people in Acre, Brazil.

The Brazilian and Peruvian governments rely on satellite images to monitor isolated Indians, but the findings aren't made public, leaving advocates in the dark. FUNAI, the Brazilian agency that oversees territories inhabited by uncontacted tribes, "is under constant attack from the 'agribusiness bloc' of politicians in Congress who are determined to overturn hard-won indigenous rights," says Fiona Watson, of Survival International.

Walker's publications don't pinpoint where villages are located, but he acknowledges that someone might be able to exploit his data to discover the Indians. That possibility worries Glenn Shepard, an anthropologist at the Goeldi Museum in Brazil: "If anyone can find them, what's to keep some unethical reality TV producer from trying to go in and make a show?" Walker defends the research as critical: "We want people to be knowledgeable about the problem and thinking about solutions." **–CATHERINE ELTON**

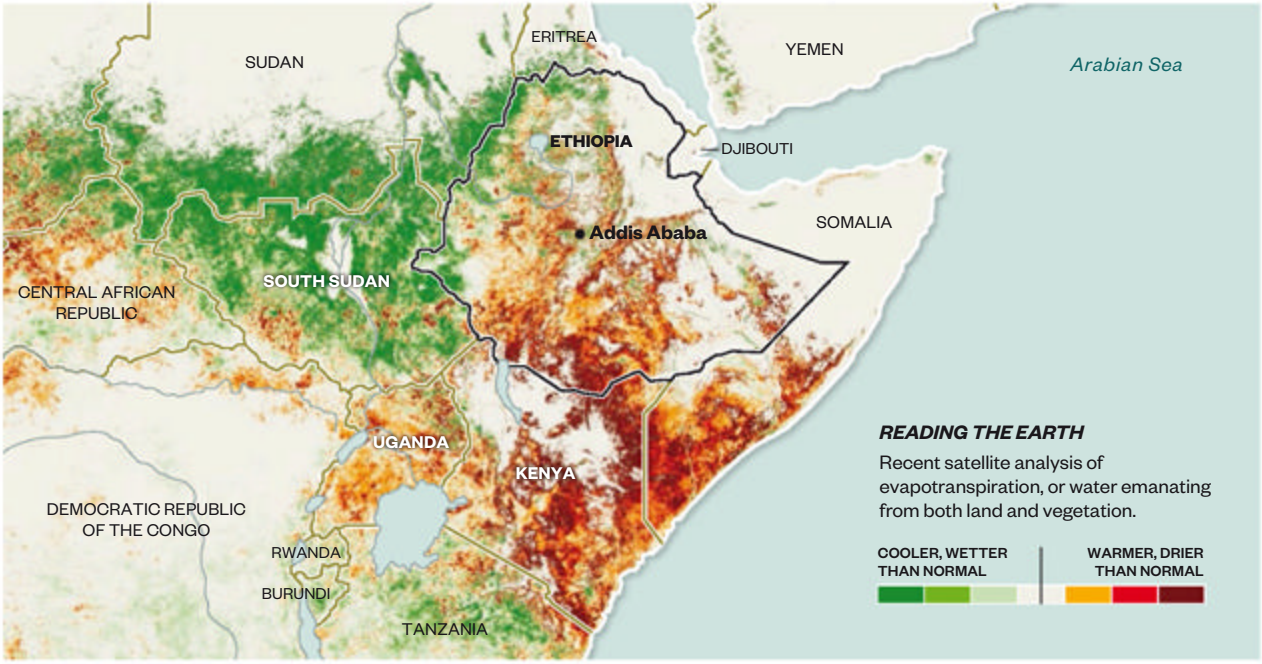
published in academic journals, taught graduate-level university courses and gave talks in places as far-flung as Jordan and Sri Lanka. Before long, people were calling from all over, wanting his algorithms for their own problems. Could he look at whether irrigation in Afghanistan's river basins was returning to normal after years of drought and war? What about worrisome levels of groundwater extraction in America's Pacific Northwest? Was he free for the National Water Census?

He'd started small. A man he met on a trip to Ethiopia told him that 5,200 people had died of malaria in three months in a single district in the Amhara region. Senay wondered if satellites could help. He requested malaria case data from clinics across Amhara and then compared them with satellite readings of rainfall, land greenness and ground moisture—all factors in where malaria-carrying mosquitoes breed. And there it was, almost like magic: With satellites, he could predict the location, timing and severity of malaria outbreaks up to three months in advance. "For prevention, early warning is very important for us," Abere Mihretie, who leads an anti-malaria group in Amhara, told me. With $2.8 million from the National Institutes of Health, Senay and Michael Wimberly, an ecologist at South Dakota State University, built a website that gives Amhara officials enough early warning to order bed nets and medicines and to take preventive steps such as draining standing water and counseling villagers. Mihretie expects the system—which will go live this year—to be a lifesaver, reducing malaria cases by 50 to 70 percent.

Senay had his next epiphany on a work trip to Tanzania in 2005. By the side of the road one day, he noticed cattle crowding a badly degraded water hole. It stirred memories of childhood, when he'd watched cows scour riverbeds for trickles of water. The weakest got stuck in the mud, and Senay and his friends would pull them out. "These were the cows we grew up with, who gave us milk," he says. "You felt sorry."

Senay geo-tagged the hole in Tanzania, and began reading about violent

SATELLITE IMAGE BY DIGITALGLOBE



MAP BY GUILBERT GATES; SOURCE: EROS

conflict among nomadic clans over access to water. One reason for the conflicts, he learned, was that nomads were often unaware of other, nearby holes that weren't as heavily used and perhaps just as full of water.

Back in South Dakota, Senay found he could see, via satellite, the particular Tanzania hole he'd visited. What's more, it gave off a distinct "spectral signature," or light pattern, which he could then use to identify other water holes clear across the African Sahel, from Somalia to Mali. With information about topography, rainfall estimates, temperature, wind speed and humidity, Senay was then able to gauge how full each hole was.

Senay and Jay Angerer, a rangeland ecologist at Texas A&M University, soon won a $1 million grant from NASA to launch a monitoring system. Hosted on a U.S. Geological Survey website, it tracks some 230 water holes across Africa's Sahel, giving each a daily rating of "good," "watch," "alert" or "near dry." To get word to herders, the system relies on people like Sintayehu Alemayehu, of the aid group Mercy Corps. Alemayehu and his staff meet with nomadic clans at village markets to relay a pair of satellite forecasts—one for water-hole levels, another for pasture conditions. But

In remote parts of the world, even good-enough data can go a long way toward "helping solve big important issues."

such liaisons may soon go the way of the switchboard operator. Angerer is seeking funding for a mobile app that would draw on a phone's GPS to lead herders to water. "Sort of like Yelp," he told me.

Senay was becoming a savant of the data workaround, of the idea that good enough is sometimes better than perfect. Doppler radar, weather balloons, dense grids of electronic rain gauges simply don't exist in much of the developing world. Like some MacGyver of the outback, Senay was proving an "exceptionally good detective" in finding serviceable replacements for laboratory-grade data, says Andrew Ward, a prominent hydrologist who was Senay's dissertation adviser at Ohio State. In remote parts of the world, Ward says, even good-enough data can go a long way toward "helping solve big important issues."

And no issue was more important to Senay than his homeland's precarious food supply.

Ethiopia's poverty rate is falling, and a new generation of leaders has built effective programs to feed the hungry in lean years. But other things have been slower to change: 85 percent of Ethiopians work the land as farmers or herders, most at the subsistence level, and less than 1 percent of agricultural land is irrigated. That leaves Ethiopia, the second most populous country in Africa, at the mercy of the region's notoriously fickle rains. No country receives more global food aid.

Famine appears in Ethiopia's historical record as early as the ninth century and recurs with an almost tidal regularity. The 1973 famine, which killed tens of thousands, led to the overthrow of Emperor Haile Selassie and the rise of an insurgent Marxist government known as the Derg. The 1984 famine helped topple the Derg.

Famine often has multiple causes: drought, pestilence, economies overdependent on agriculture, antiquated farming methods, geographic isolation, political repression, war. But there was a growing sense in the latter decades of the 20th century that science could play a role in anticipating—and heading off—its worst iterations. The United

Nations started a basic early-warning program in the mid-1970s, but only after the 1980s Ethiopian crisis was a more rigorously scientific program born: USAID's Famine Early Warning Systems Network (FEWS NET).

Previously, "a lot of our information used to be from Catholic priests in, like, some little mission in the middle of Mali, and they'd say, 'My people are starving,' and you'd kind of go, 'Based on what?'" Gary Eilerts, a veteran FEWS NET official, told me. Missionaries and local charities could glimpse conditions outside their windows, but had little grasp of the broader severity and scope of suffering. Local political leaders had a clearer picture, but weren't always keen to share it with the West, and when they did, the West didn't always trust them.

The United States needed hard, objective data, and FEWS NET was tasked with gathering it. To complement their analyses of food prices and economic trends, FEWS NET scientists did use satellites, to estimate rainfall and monitor land greenness. But then they heard about a guy in small-town South Dakota who looked like he was going one better.

Senay knew that one measure of crop health was the amount of water a field gave off: its rate of "evapotranspiration." When plants are thriving, water in the soil flows up roots and stems into leaves. Plants convert some of the water to oxygen, in photosynthesis. The rest is "transpired," or vented, through pores called stomata. In other words, when fields are moist and crops are thriving, they sweat.

Satellites might not be able to see the land sweat, but Senay wondered if they could *feel* it sweat. That's because when water in soil or plants evaporates, it cools the land. Conversely, when a lush field takes a tumble—whether from drought, pests or neglect—evapotranspiration declines and the land heats. Once soil dries to the point of hardening and cracking, its temperature is as much as 40 degrees hotter than it was as a well-watered field.

See more photographs of Senay's work in Ethiopia at **Smithsonian.com/satellite**

NASA's Aqua and Terra satellites carry infrared sensors that log the temperature of every square kilometer of earth every day. Because those sensors have been active for more than a decade, Senay realized that a well-crafted algorithm could flag plots of land that got suddenly hotter than their historical norm. In farming regions, these hotspots could be bellwethers of trouble for the food supply.

Scientists had studied evapotranspiration with satellites before, but their methods were expensive and time-consuming: Highly paid engineers had to manually interpret each snapshot of land. That's fine if you're interested in one tract of land at one point in time.

But what if you wanted every stitch of farmland on earth every day? Senay thought he could get there with a few simplifying assumptions. He knew that when a field was perfectly healthy—and thus at peak sweat—land temperature was a near match for air temperature. Senay also knew that a maximally sick field was a fixed number of degrees hotter than a maximally healthy one, after tweaking for terrain type.

So if he could get air temperature for each square kilometer of earth, he'd know the coldest the land there could be at that time. By adding that fixed number, he'd also know the hottest it could be. All he needed now was NASA's actual reading of land temperature, so he could see where it fell within those theoretical extremes. That ratio told you how sweaty a field was—and thus how healthy.

Senay found good air temperature datasets at the National Oceanic and Atmospheric Administration and the University of California, Berkeley. By braiding the data from NASA, NOAA and Berkeley, he could get a computer to make rapid, automated diagnoses of crop conditions anywhere in the world. "It's data integration at the highest level," he told me one night, in the lobby of our Addis hotel.

The results might be slightly less precise than the manual method, which factors in extra variables. But the upsides—how much of the world you saw, how fast you saw it, how little it cost—wasn't lost on his bosses. "Some more academically oriented people reach an impasse: 'Well, I don't know that, I can't assume that, therefore I'll stop,'" says James Verdin, his project leader at USGS, who was with us in the Rift Valley. "Whereas Gabriel recognizes that the need for an answer is so strong that you need to make your best judgment on what to assume and proceed."

FEWS NET had just one other remote test of crop health: satellites that gauge land greenness. The trouble is that stressed crops can stay green for weeks, before shading brown. Their temperature, on the other hand, ticks up almost immediately. And unlike the green test, which helps only once the growing season is underway, Senay's could read soil moisture at sowing time.

The Simplified Surface Energy Balance model, as it is called, could thus give officials and aid groups several weeks' more lead time to act before families would go hungry and livestock would begin to die. Scientists at FEWS NET's Addis office email their analyses to 320 people across Ethiopia, including government officials, aid workers and university professors.

Biratu Yigezu, acting director general of Ethiopia's Central Statistical Agency, told me that FEWS NET fills key blanks between the country's annual door-to-door surveys of farmers. "If there's a failure during planting stage, or if there's a problem in the flowering stage, the satellites help, because they're real time."

One afternoon in the Rift Valley, we pulled the Land Cruisers alongside fields of slouching corn to speak with a farmer. Tegenu Tolla, who was 35, wore threadbare dress pants with holes at the knees and a soccer jersey bearing the logo of the insurance giant AIG. He lives with his wife and three children on whatever they can grow on their two and a half acre plot.

This year was a bust, Tolla told Senay, who chats with farmers in his native Amharic. "The rains were not there." So Tolla waited until August, when some



ZACHARIAS ABUBEKER

Gofa Hundie, a farmer in the Arsi area. Scientists predict Ethiopia will be "hard hit" by climate change, with crop yields plunging 22 percent by 2080.

rain finally came, and sowed a short-maturing corn with miserly yields. "We will not even be able to get our seeds back," Tolla said. His cattle had died, and to feed his family, Tolla had been traveling to Adama for day work on construction sites.

We turned onto a lumpy dirt road, into a field where many of the teff stalks had grown just one head instead of the usual six. (Teff is the fine grain used to make injera.) Gazing at the dusty, hard-packed soil, Senay had one word: "desertification."

The climate here was indeed showing signs of long-term change. Rainfall in the south-central Rift Valley has dropped 15 to 20 percent since the mid-1970s, while the population—the number of mouths to feed—has mushroomed. "If these trends persist," FEWS NET wrote in a 2012 report, they "could leave millions more Ethiopians exposed to hunger and undernourishment."

Over the next few days we spiraled down from the highlands into harder-hit maize-growing areas and finally into scrublands north of the Kenyan border, a place of banana plantations and roadside baboons and throngs of cattle, which often marooned our vehicles. At times, the road seemed a province less of autos than of animals and their child handlers. Boys drove battalions of cows and sheep, balanced jerrycans of water on their shoulders and stood atop stick-built platforms in sorghum fields, flailing their arms to scare off crop-devouring queleas, a type of small bird.

Almost everywhere we stopped we found grim alignments between the red and orange dots on Senay's maps and misery on the ground. Senay was gratified, but in the face of so much suffering, he wanted to do more. Farmers knew their own fields so well that he wondered how to make them players in the early warning system. With a mobile app, he thought, farmers could report on the land beneath their feet: instant ground-truthing that could help scientists sharpen their forecasts.

What farmers lacked was the big picture, and that's what an app could give back: weather predictions, seasonal forecasts, daily crop prices in nearby markets. Senay already had a name: Satellite Integrated Farm Information, or SIFI. With data straight from farmers, experts in agricultural remote sensing, without ever setting foot on soil, would be a step closer to figuring out exactly how much food farmers could coax from the land.

But soil engulfed us now—it was in our boots, beneath our fingernails—and there was nothing to do but face farmers eye to eye.

"Allah, bless this field," Senay said to a Muslim man, who'd told us of watching helplessly as drought killed off his corn crop.

"Allah will always bless this field," the man replied. "We need something more."

National Treasure

Monolith

The newly acquired archives of Arthur C. Clarke shed new light on a futuristic giant

I was once a teen from Texas, living in southern India during the early 1970s (my father had been dispatched abroad in the petrochemical-employment diaspora). That was how, as a science fiction-obsessed kid, I ended up in an audience in Madras when Sir Arthur C. Clarke arrived in the city on a lecture tour. Clarke, a British expat who made his home in the nearby island nation of Sri Lanka, was the first science fiction writer I'd ever met.

I stared in awe at the visionary sage as he addressed a crowd who included the city's businessmen, clad in white cotton dhotis and jubbahs, sitting in wooden chairs in an air-conditioned hotel ballroom. Clarke told his audience two important things: Information should no longer be printed on paper, and Indians should keep up the good work with their space program. After his speech, Clarke, a bespectacled, round-shouldered man, joked with me in a donnish fashion as he signed a tall stack of my paperbacks. I'd innocently brought along my entire Arthur Clarke fiction and nonfiction collection, which filled a large bag.

Now it's 2015. An Indian satellite orbits Mars, while I'm in my home study poring over pages from the Arthur Clarke personal papers, sent to me in a form Clarke would have appreciated: as electronic files. As it turns out, Sir Arthur C. Clarke, CBE, is likely the only author of fiction whose papers happen to be archived in a repository devoted to outer space—the Smithsonian National Air and Space Museum's Udvar-Hazy Center. Smithsonian curator Martin Collins and archivist Patti Williams recently acquired some 85 cubic feet of Clarke's paper data, including photographs, shipped from Sri Lanka by FedEx.

One of the oldest and most numinous items is a battered high-school notebook. Its pages feature neat, hand-lined grids in which an adolescent Clarke lists his precious science fiction possessions. He rates the works, too—"good," "very good" and the rare "very very good." Young Arthur is particularly keen on H.G. Wells and Edgar Rice Burroughs, as indeed I was at his age—except that I had the benefit of reading heaps of Arthur C. Clarke.

I noted, also, a few choice items related to that famous business with Stanley Kubrick. (Among the new Smithsonian holdings are an early draft of the novel *2001: A Space Odyssey*.) The two of them, director and novelist, are conspiring to make what Kubrick describes in a letter to Clarke as a "really good science fiction movie," because they both know that there is no such thing—not yet.

As they worked together, conjuring up the novel and the film, correspondence reveals a preoccupation with "the Cube" (later transmuted into the

by Bruce Sterling



An early draft of the novel *2001: A Space Odyssey*

PHOTOGRAPH BY **Cade Martin**



Monolith). Responding to Clarke's suggestion in 1966 that the Cube communicate directly with the man-apes who would one day populate the film, Kubrick instead advocates an enigmatic presence: "We see only the hypnotic image appear and the spellbound faces of the man-apes."

The "really good science fiction movie" was supposed to take two years to complete (it took four); it was $4 million over budget; the film nearly bombed in American theater chains before hippies flocked to watch it—a tale of spine-tingling terror, almost.

2001: A Space Odyssey bears the imprint of its source, Clarke's short story "The Sentinel." Clarke dashed off that lunar tale in 1948, only to have his big idea blow everybody's minds a full 20 years later. Lags of that length were rather typical in the visionary's life.

Clarke, a British émigré in Sri Lanka, must have been an ideal collaborator for Kubrick, an American émigré in Britain. In his limpid, clear, well-typed correspondence, Clarke briefs Kubrick on a dazzling panoply of severely weird topics: paleo-anthropology, extraterrestrial intelligence, scuba diving, the proper choice in home telescopes. Clarke cares not one bit for Hollywood glamour. He's always informative, yet never intrusive.

Sri Lanka was kind to Clarke. For years, he shipped his personal papers back to Britain for alleged safekeeping, then finally took the entire lot back to the island where he really lived, despite the risks of Sinhalese typhoons, tsunamis and civil war. His soul was British, while his mind was frankly extraterrestrial; eventually the lore had to go where the heart was. Now that cache resides in the museum where history probably wants it to be.

There were two kinds of fantasies in the Space Age: rocket-powered geopolitical fantasies with budgets of billions of dollars and rubles, and poetic paper fantasies made up by science fiction writers, especially one lone genius with an aqualung and a sarong. As decades pass, it gets harder for posterity to tell those world views apart. But Clarke always knew there was no real difference.

PLASTIC PLANET

A BEACHCOMBING ARTIST'S STUNNING IMAGES SHOW WE'RE IN **A SEA OF TROUBLE**

PHOTOGRAPHS BY
Mandy Barker

TEXT BY
ELIZABETH ROYTE

So much plastic is discarded around the world that 8.8 million tons end up in the ocean every year, according to a recent analysis of waste disposal in 192 coastal nations, the most comprehensive study of its kind. China contributes the most, an estimated 2.4 million tons a year, followed by Indonesia at nearly 900,000 tons. The United States ranks 20th, contributing some 80,000 tons. If trends continue, the researchers predict, the toll worldwide will double by 2025, to about 100 million pounds per day. The plastic swirls in giant gyres in the open oceans, collecting in "garbage patches" (though concentrations are too low to resemble piles of trash). Most of the plastic is degraded into small particles, eaten by sea creatures or submerged. In remote waters off Kamchatka, researchers scanning the floor three miles below the surface found as many as 185 tiny plastic litter pieces per square foot. The disaster is largely invisible but for one place—shorelines. For *Hong Kong Soup: 1826* (the number refers to the metric tons of plastic added to the city's landfills each day), Britain-based artist Mandy Barker photographed plastic from Hong Kong beaches and layered her images for a phantasmagorical, deep-space eeriness. "I wanted to create the feeling of no boundaries," she says, "because plastic just goes on and on."

TRANSFORM **Barker collected debris from some 30 Hong Kong beaches, averaging five toys a day.**

See more of Barker's project at Smithsonian.com/plastic





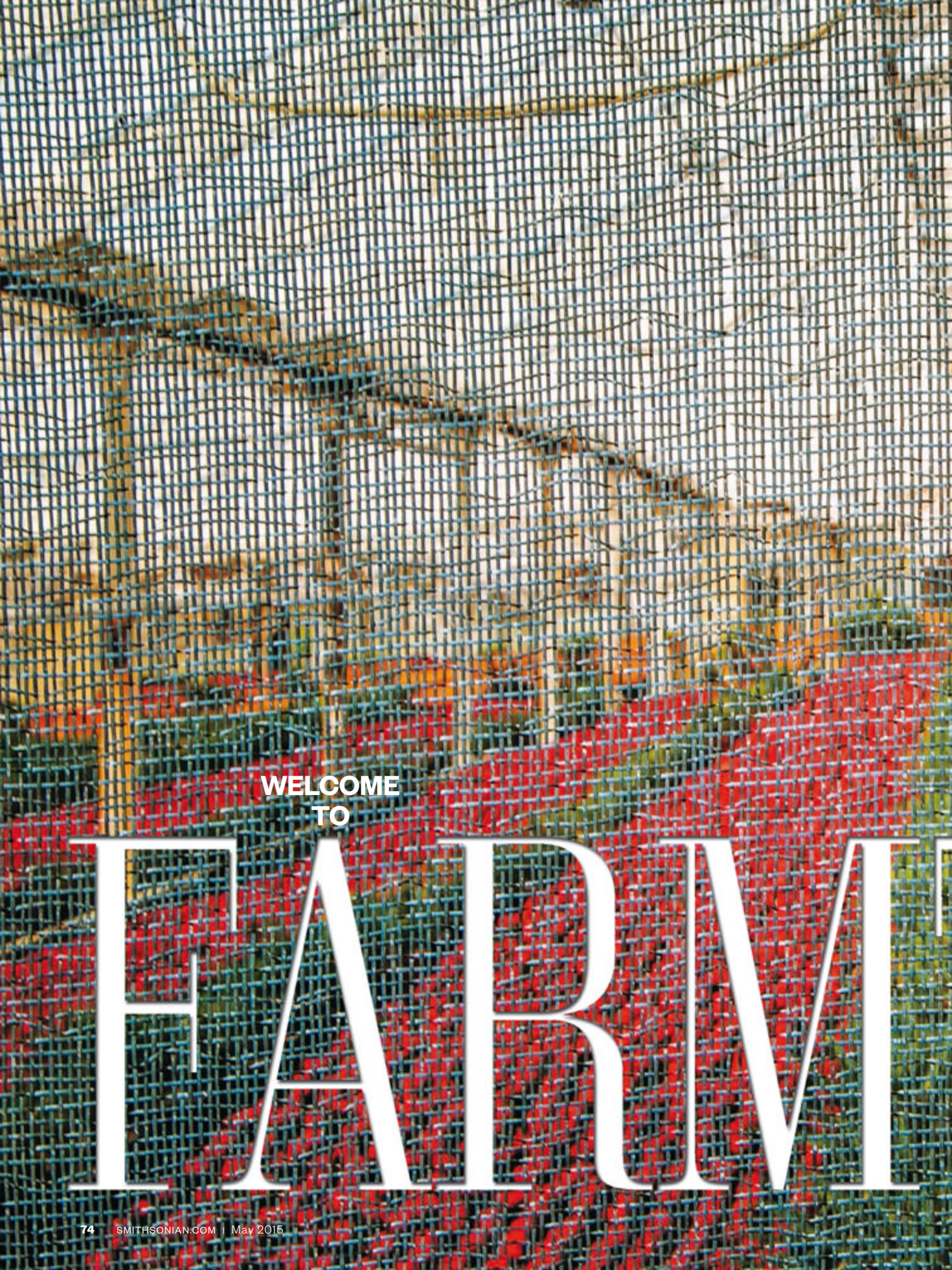
SPILT
During Typhoon Vicente in 2012, containers filled with plastic pellets toppled from a freighter into the South China Sea. Called "nurdles," the pellets had to be vacuumed from beaches.







POLYSTYRENE *(left)*
LOTUS GARDEN *(this page)*
Hong Kong fishermen store their daily catch in plastic foam containers, and plastic flowers decorate homes, temples and parks. Other debris that commonly washes ashore: shoes, novelty pens, toilet seats and TVs. "You couldn't possibly pick up everything," says Barker.


WELCOME
TO
FARM



HOPIA

A NEW KIND OF FOOD-FOCUSED SUBURB IS SPROUTING ACROSS AMERICA. BUT IS IT SUSTAINABLE?

BY Franz Lidz

PHOTOGRAPH BY **BRINSON + BANKS**

At the cusp of the Great Depression, the humorist S.J. Perelman and his wife moved from Manhattan to a farm in Bucks County, Pennsylvania. Fifteen years of rusticating left him with "a superb library of mortgages, mostly first editions, and the finest case of sacroiliac known to science." Perelman recounted his picturesque miseries as a country squire in the 1947 collection *Acres and Pains*, which introduced readers to his real estate agent (Dewey Naïveté), his attorney (Newmown Hay, of Ashen, Livid & Hay) and his farm (Rising Gorge), which he describes as "an irregular patch of nettles bounded by short-term notes containing a fool and his wife who didn't know enough to stay in the city."

Perelman's rueful tale gained its widest cultural currency when it was adapted into the 1960s sitcom "Green Acres," about a New York lawyer who pines for a simpler life, and, over the objections of his socialite wife, buys a farm, sight unseen. His own dewy naiveté was neatly summed up in the theme song: *Green Acres is the place to be / Farm livin' is the life for me / Land spreadin' out so far and wide / Keep Manhattan, just give me that countryside.*



Possibly the most enthusiastic embrace of farm livin' these days is found deep in the woods of Chattahoochee Hill Country, southwest of Atlanta. There lies Serenbe, a 1,000-acre suburban Eden comprising two neighborhoods (and counting) bunched around Ye Olde English village-style town centers.



Daron "Farmer D" Joffe climbs a compost heap at the nonprofit farm he runs in California. His new project includes a suburban "food forest" linked to a public trail.

BRINSON + BANKS

The hamlets are shaped like omegas to conform to the undulations of the land. Peach and pecan trees shoot up from the sidewalks; goats and llamas browse in dells; and lambs caper along the walking trails that curl through glens and glades.

Everything has been assiduously planned. Cottages and co-ops are built to energy-efficient EarthCraft specs. Waste water is filtered in a biological treatment system and reused for irrigation. The town centers are dotted with upmarket galleries, and a nonprofit cultural institute stages plays and sponsors artists in residence. There are stables, spas and, not least, a farm that produces 350 varieties of organic fruit, vegetables, herbs and flowers.

"When I first visited here, I thought Serenbe felt artificial," says E.C. Hall, a resident and retired college professor. "I thought of the prefabricated town in *The Truman Show*, created to exist separately from the rest of the world. That changed when I walked around and met people every few yards. I realized we all had a similar desire for community."

Serenbe is perhaps the country's most popular and profitable "agritopia," the leafiest, farmiest of all the nascent trends in real estate, in which agrarian-focused housing schemes are anchored by farmland rather than, say, greenswards, man-made lakes or golf courses. Ranches, gardens and vineyards are major selling points. There are already dozens of agritopian developments and, fueled by the local-food movement, emerging widespread environmental consciousness, Perelmanesque romanticism and good old American marketing chutzpah, more are in the works—enough to qualify as a trend in America's preeminent rural community paper, the *New York Times*.

Agritopias are popping up like dandelions across the country, and why not? Developers are nothing if not attuned to their customers, and what the customers want is increasingly clear. At Serenbe, that's eight acres of farmland, which produce enough veggies to supply a half-dozen restaurants (three onsite), a farmer's market and a Community-Supported Agriculture

program with 120 members (most of whom live in outlying towns).

"The thing I like about the farm is that it's as real as any I've ever worked on," says Serenbe resident Rebecca Williams, a 31-year-old Atlanta native who worked at a variety of farms before she and her husband, Ross, purchased a 145-acre sheep's milk dairy just outside the development. "It's not a toy farm," she says. "It's serious agriculture." Serenbe Farms is indeed professionally run, by a young idealist named Ashley Rodgers, who makes a comfortable living and has four full-time interns to boot. (They get a monthly stipend and free housing.)

Williams calls Serenbe the "leading edge" of the new suburbs, propelled by a history of what's been shown to make people happy: physical closeness, which encourages human interaction; proximity to amenities, which creates the sense that what you need is readily at hand; green spaces, cultivated and wild, that provide places to play and explore; and varied architecture, which fosters a feeling of security, because it creates the sense that a place has existed for a long time. "All of these things create a genuine sense of safety," she says, "which is the most basic element of community and without which happiness is impossible."

The agritopia takes these principles and cleverly folds in agriculture. Everything new is invariably old. Americans have romanticized farming since the country began. In 1787, Thomas Jefferson wrote to George Washington that "Agriculture . . . is our wisest pursuit, because it will in the end contribute most to real wealth, good morals & happiness." Today's successful sales pitch includes snipping arugula from the garden and then picking apples and strawberries on the stroll home from work. The only thing missing from this fantasy are the bluebirds that take your coat as you walk in the front door.

A few years back, the pioneering architect and urban planner Andrés Duany wrote a manifesto, *Garden Cities*, proposing that agriculture woven into urbanism represented the future of our cities. "Sustainability to the point of self-sufficiency is where the market is going," he wrote. But *Garden Cities* was meant to be more than a market-indicator. It was a warning: "To make a difference in the campaign against climate change," he wrote, "agrarian urbanism must succeed in being profitable, popular and reproducible—with no downsides if possible."

Which could be a tough row to hoe.

Ever watch the "Portlandia" sketch in which a couple of earnest diners ask their server not only about the diet of the chicken they are about to consume, but exactly how much land it lived on, and its name? The server returns with pedigree papers to prove that Colin was raised on a woodland diet of sheep's milk, soy and, yes, local hazelnuts. Ultimately, the diners leave the table to visit the farm and see for themselves how Colin was brought up.

The residents of Bainbridge Island have some of the do-it-ourselves urban progressive preciousness associated with the food scene in Portland, Oregon, some 200 miles south. Within five minutes of entering a downtown coffee shop (where doughnuts are "hand-forged"), I hear enough buzzwords—fair trade, house-made, artisanal, locally sourced—to start a compost heap.

A gossamer-fine rain falls steadily across the Puget Sound, the kind of day Bainbridge Islanders call balmy. Happily, downtown is a five-minute stroll from Grow Community, at eight acres the largest planned solar settlement in Washington state. "The population is 30 percent environmentalists, 30 percent lawyers and 30 percent people who are concerned about the environment and have lawyers," says project manager Greg Lotakis. "Somehow, that adds up to 100 percent."

Lotakis escorts me to the Village, Grow Community's first completed residential neighborhood. Streets are named Seed Path, Root Path and Sprout Path, as befits the setting for an urban farm. Raised pea-patch beds fronting each unit recall World War II victory gardens. Banks of berry bushes line the walkways. The 42 homes and apartments are, for the most part, wedged tightly together, the better to make use of limited space and encourage social interaction. Exteriors are Northwest Modern patchworks of board-and-batten cladding, and panels of concrete and corrugated steel. The cedar siding, I'm assured, comes from sustainably managed forests within 500 miles. There's so much talk of "leaving small footprints" that I feel like I'm in a colony of elves.

For all its affectations and lack of racial diversity (Lotakis: "There are a lot of white people"), Grow Community is an honest attempt to change the way we live—a contemporary reboot of an old-fashioned American utopia. During the 19th century, when Utopianism had its heyday, the tapestry of sects included Brook Farm's Transcendentalists, the free lovers of Oneida, New York, and the Shakers, religious cultists so called because they trembled during worship. The Shakers' biggest problem was that they practiced celibacy, hence they are no longer with us. For them, at least, the road to Utopia was a dead end.

At Grow, Utopian living takes some getting used to. Though berries are there for the taking, some residents are reluctant pluckers. "Folks who weren't involved with the gardens tend to be harvest-shy," says resident Ron Kaplan. "Some berries went bad on the vine." So Kaplan put up signs: "Pick Me."

Some Village people—resident volunteers—would like to install a public composting machine; others cluck about henhouses that are solar-powered and self-propelled. When chicken coops do come to Grow, don't be surprised if one of the roosters answers to Colin.

Of all the many things we learned from watching the first season of "The Real Housewives of Orange County," the most jarring may be the fact that, at the time, seven million American

See more photographs of life on the suburban farm at **Smithsonian.com/farms**



“The autumn harvest produced lots of beans and squash. It wasn’t exactly the Soviet Union model of centralized planning.”

families lived in gated developments.

These modern suburban fortresses are the kinds of places that mostly white and affluent Americans choose to live in when they want to feel safe—from crime, from economic uncertainty, from Americans who are not mostly white and affluent.

Today I’m touring Rancho Mission Viejo, a massive, partially gated community assembled on a swath of amber hills and grasslands where the Real Cattle of Orange County still graze. A brilliant mid-winter sun blooms over the Guest House, a welcome center not unlike the one at Disneyland, a half-hour drive up Interstate 5. The surrounding hillsides are speckled with tens of thousands of fruit trees. Inside, an immense property map hangs over a shelf of plastic lemons and avocados. “Homebuyers can enjoy the exclusive vistas of the citrus groves,” the Guest House greeter tells me, handing me a plastic bottle of water that bears the label: “The Ranch. Drink It In.”

Some might see the nearer roots of developments like Rancho Mission Viejo and other suburban agritopias in the community of Prairie Crossing, the Illinois hamlet founded in 1993 with a 100-acre organic farm and a reconstructed plain at its heart. But the closer prototype might be Columbia, Maryland.

In 1967, the visionary developer James Rouse led several hundred disillusioned city dwellers on a pilgrimage to Columbia. “There will be complete integration of races and economic groups,” he declared. Rouse’s Promised Land, midway between Baltimore and Washington, D.C., was founded on 14,000 acres of cow pasture. He called it the Next America.

Rouse conceived nine villages ringing a shared town center, with clustered housing that encouraged neighborliness, a scheme later picked up by the leaders of the New Urbanism movement. “Columbia is a garden for growing people,” was Rouse’s description. Yet lurking behind Rouse’s egalitarian pronouncements was a shrewd capitalist. When he was not playing the Pied Piper, he was a mortgage banker. He made his fortune assembling other people’s money and charging interest for it, and Columbia’s first wave of utopians were followed by speculators buying homes for 5 percent down and getting equity as fast as possible. As Rouse’s people garden bloomed—Columbians now number about 100,000—housing prices swelled as if dosed with Miracle-Gro.

Grow Community’s “edible landscaping” includes pea patch garden beds. Residents like Lisa Ellis volunteer to tend to the gardens.

By the early ’80s, New Urbanism had

MICHAEL HANSON; PP. 80&81: ANDRES GONZALEZ



Serenbe's founder, Steve Nygren (with daughter, Garnie), discovered the property on an outing to the countryside. The 420 residents include Rebecca Williams (right), who owns sheep.



sprung up to pitch itself against what it saw as the lifeless, land-guzzling sprawl of suburbia. It proposed that beauty—a virtue low on planners' agendas for much of the last century—mattered as much as function. In model New Urbanist towns like Florida's Celebration and Seaside (the latter designed by Andrés Duany and his wife, Elizabeth Plater-Zyberk), America's alienating car culture was replaced by a matrix of foot and bike paths; porches returned to the street-facing side of homes; and parks and playgrounds became communal meeting grounds.

Among New Urbanism's snarkier jeremiads was James Howard Kunstler's 1993 book *The Geography of Nowhere*, which savaged the burbs' "immersive ugliness"—and then it got mean. His catalog of the "brutal" and "spiritually degrading" landscapes of suburbia encompassed "the jive-plastic commuter tract home wastelands, the Potemkin village shopping plazas with their vast parking lagoons, the Lego-block hotel complexes, the 'gourmet mansardic' junk-food joints, the Orwellian office 'parks' featuring buildings sheathed in the same reflective glass as the sunglasses worn by chain-gang guards, the particle-board garden apartments rising up in every meadow and cornfield, the freeway loops around every big and little city with their clusters of discount merchant marts, the whole destructive, wasteful, toxic, agoraphobia-inducing spectacle that politicians proudly call 'growth.'"

Asked recently if he had a solution to our problems, Kunstler said, "I don't like talking about 'solutions.' I prefer talking about intelligent responses."

Under the sprawling California sunshine at Rancho Mission Viejo, the Guest House greeter drives me through the village of Gavilán, an exclusive enclave reserved for residents aged 55 and older—a Tomorrowland for housewives and househusbands with rapidly dwindling tomorrows.

Gavilánters enjoy privacy behind an electronically monitored, double-gated entrance and amenities like a lounge with tapas and a happy hour. "Rancho Mission Viejo cultivates real community and an authentic, fresh new way of living," the greeter says, as we drive through a bewildering maze of gingerbread casitas and Spanish-style condos.

Eventually, we reach a cul-de-sac with no exit, no parked cars, no people on the sidewalk. In fact, no sidewalks. At the end of the street is a raised plot for growing vegetables, herbs and fruits. It's enclosed by a daunting iron fence and protected by a security system requiring an access code.

At Gavilán, even the cabbages and cauliflowers live in their own gated development.

Joffe was born in South Africa and grew up in Atlanta. During his freshman year at the University of Wisconsin-Madison, a deli sandwich changed his life. As he was about to bite in, he paused to ponder the ingredients: the turkey, the tomato, the lettuce, the slice of Swiss. He wondered why he knew so little about how that sandwich came to be. "I was inspired to grow a sandwich from scratch," Joffe says.

He dropped out of school to apprentice at a biodynamic farm. Within a couple years, he used his bar mitzvah money to make a down payment on 175 acres in southwest Wisconsin. Since then he has set up dozens of organic farms and gardens in prisons, schools and resorts; opened a retail urban farm store in Atlanta; put out his own line of sawhorse coffee tables; and written a gardening handbook called *Citizen Farmers*, which includes a meditative section on "composting for the soul." (Equal to Joffe's passion for farming is his passion for Judaism.)

"The thing I like about the farm is that it's as real as any I've ever worked on. It's not a toy farm. It's serious agriculture."

While moonlighting as a gentleman farmer, S.J. Perelman made several important discoveries. One was that there are no chiggers in an air-conditioned movie theater. Another, "that a corner delicatessen at dusk is more exciting than any rainbow."

Daron Joffe concedes the first point, but quibbles with the second. The 38-year-old agricultural consultant—or, as he puts it, entre-manure—lives to make a difference in the world one homegrown organic heirloom tomato at a time. Joffe, who goes by the handle Farmer D, is lean and wiry, with skin the color of butter toffee. He has about him a sort of intimation of abundance, as if, like a magician, he might suddenly reach into a pocket and draw forth a goat's horn overflowing with cherries, violets and spinach.

Under a stingy brim straw hat of indeterminate age, Joffe strolls past a wild meadow of nasturtiums, beets, carrots and celery—a cover crop medley based on the feedback of food banks near the nonprofit farm he runs in Encinitas, a small coastal town north of San Diego. He gathers some flowers and lays them in the crook of his right arm. The sun is shining.

Joffe was also the first farm manager at Serenbe, but he left after two years. "I moved on," he says. He's still high on agritopias, if not all of their manifestations. "Agriculture can be a hard concept for developers to wrap their heads around," he told me. The farm itself is too often "an unintegrated afterthought," squeezed into a corner of the development, and the hired farmers have little incentive to feel like a part of the community. Joffe says the mentality of agridevelopers tends to be, "Let's get a random local farmer, tell him he can use the land for free and just let him farm"—essentially feudal serfs working the fields of wealthy landowners.

"The farmer wants to have equity and something to call his own," says Joffe, who is married with two small kids. "You want to raise your family in these neighborhoods—a lot of which



Kendal at Granville resident Rosemary J. basks in the simple pleasures found in her patio garden.

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are not affordable. When you plant a fruit tree, you want to know that your grandkids are going to eat off it. In these communities, those things can be real challenges." According to the U.S. Department of Agriculture, 91 percent of American farm households—those which devote their livelihoods to the practice and lifestyle on agricultural land far from urban centers—have at least one family member working a non-farm job to make ends meet.

"It's well known that local specialty crop farming is difficult at best and pretty much not profitable anywhere," says Quint Redmond. "It's why there are very few farmers." Redmond sees himself as a prophet of a true agritopian future. Or, rather, an agri*burbian* future: He and his wife, Jenny, run Agriburbia®, a Colorado land-planning company. They launched the operation hoping to transform the nation's burbs by converting 31 million acres of idle lawn to food production. Redmond envisions sowing golf course fairways with kale and corn and edging greens in chives and basil—maximum efficiency, while more or less turning a day on the links into an exercise in salad making.

So far his schemes have been unrealized. After 12 years, he's developed one three-quarter-acre model garden outside Denver and has proposals in the design phase for thousands of acres of other people's private farmland—stockpiled by eager agritopians-to-be in anticipation of the coming Agriburbia®.

I thought back to the enlightened souls at Serenbe, full of confidence and communal feeling. Rebecca Williams, the sheep farmer, was sure that the model was reproducible. "All it takes is a handful of people with a shared vision, and a willingness to invest in the kind of development that people are enamored with and willing to pay for," she said. Custom-built homes in Serenbe can run as high as $3 million. "Who wouldn't want to live here?" asked Jana Swenson, who's married to the retired professor E.C. Hall and has lived in a couple of houses in the community. "That is, if you could afford it."

Money—or lack of it—is no longer the main obstacle to Joffe. Last year the Leichtag Foundation, a Jewish philanthropic nonprofit organization, put him in charge of its new community agricultural center in Encinitas. The foundation had purchased the remaining 68 acres of the once vast Ecke Ranch, the nation's largest producer of poinsettias, whose other 850 acres had been sold to developers in the 1990s to transform the farmland into neighborhoods and shopping centers.



Serenbe has three restaurants in additon to its eight-acre farm. The chef of the Farmhouse, Thaddeus Barton, picks through freshly harvested beets.

ANDRES GONZALEZ

The new property is smack in the middle of a jumble of tract homes, but Leichtag promised to use it for the common good, not for an uncommon profit. "We're introducing a farm into an existing suburb in a grassroots way," says Joffe, who grows produce for the needy as part of the organization's food pantry outreach and commitment to the concept of *tikkun olam*, a Hebrew phrase meaning "repair the world." About a quarter of the county's population can't cover the area's high cost of living.

Last fall, his team laid the groundwork for a five-acre food forest that will be layered with plants like plum, date and pistachio trees and link up to a public trail. Whatever isn't donated to charity will be free for the taking. "Our farm project is driven by social values," Joffe says. "It's not driven by a real estate developer. It's not about selling houses. It's about getting people reconnected to food."

Developers eager to cash in on Joffe's cachet often approach him about brand partnerships, and when I ask him how he feels about real estate people jumping on the agritopia bandwagon, he tenses his body, as from a blow. "I have some concerns," he says. "I hear the jargon used and think, 'This is coming from the wrong place. These people don't get it. This makes the entire movement look bad.' By the same token, you hope there are well-considered models out there that people will look to and learn from."

Perelman, for his part, said his time in the tall rhubarbs had made him a new man. His cheeks "developed the ruddy vitality of a pail of lard," his fingers were "permanently knotted with arthritis" and his life-insurance beneficiaries discussed him "openly in the past tense."

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Reported by J. Page

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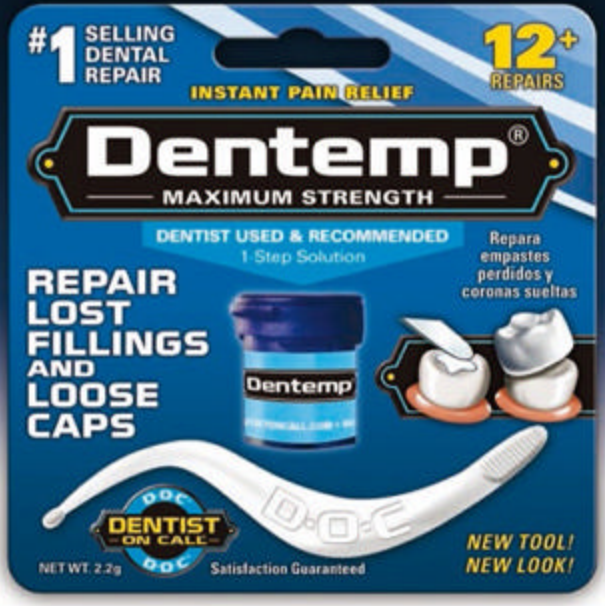
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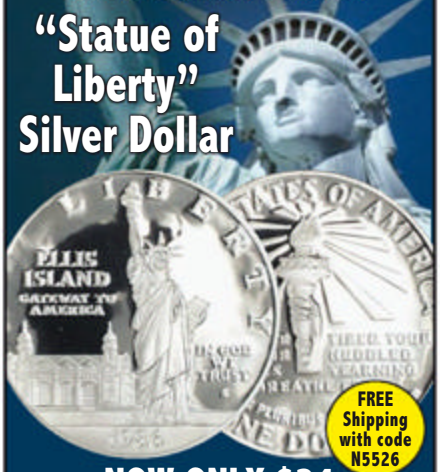
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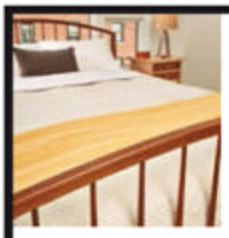
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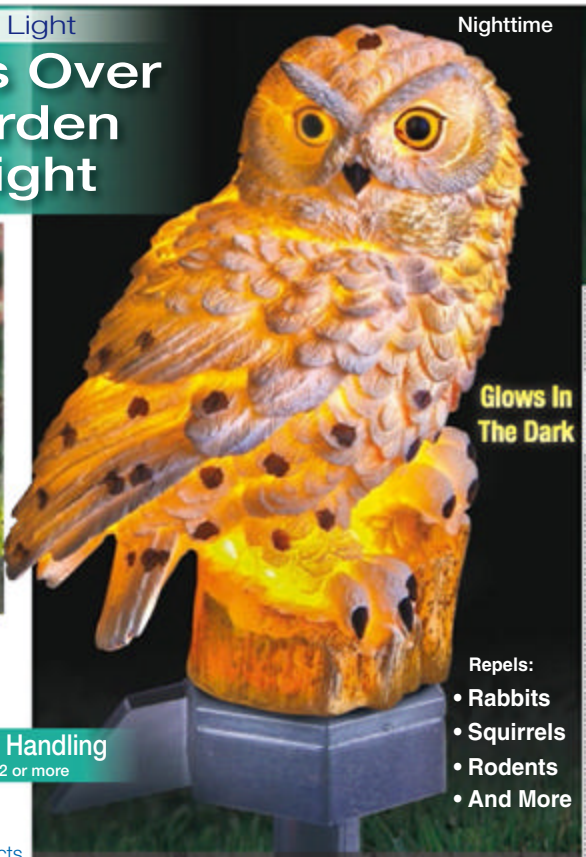
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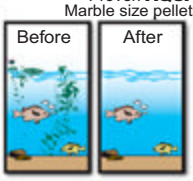


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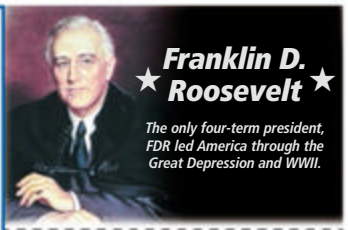
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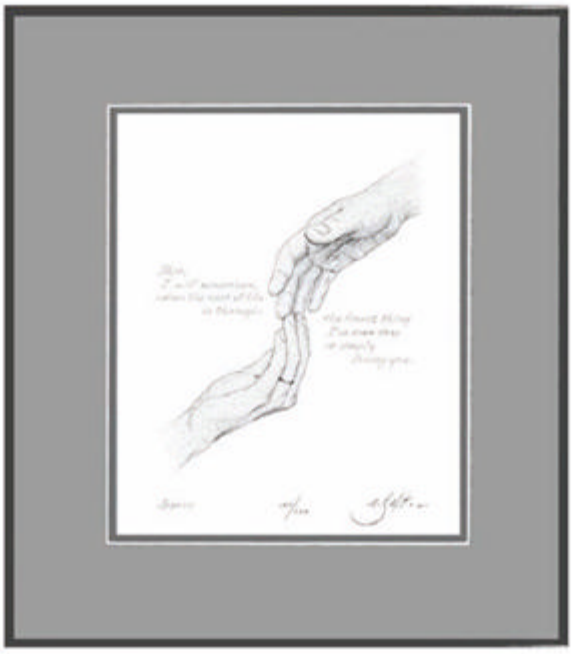
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Engineered Organs

CONTINUED FROM PAGE 43

resolution that vascular networks require. "The tech is going to have to improve a great deal before we're able to bioprint a kidney or a heart, and get blood to it, and keep it alive," Taylor says.

Researchers at Wake Forest are also experimenting with decellularized organs from both animal and human cadavers. Indeed, although Atala sees the replacement kidney as his Holy Grail, he doesn't pretend that building one will be anything but an incremental process, undertaken from a variety of angles. So while researchers at the institute and elsewhere work to refine printing the organ's external structure and internal architecture, they're also experimenting with different ways to print and grow blood vessels. At the same time, they're honing techniques to cultivate the living kidney cells necessary to make it all work, including a new project to propagate kidney cells taken from a biopsy of a patient's healthy tissue.

When we talked, Atala emphasized that his goal is to get a functioning, engineered large organ into a human being who desperately needs it, whether that organ was bioprinted or not. "Whatever technology it takes to get there," he said.

And yet he was quick to point out that the way you get there isn't unimportant: Ultimately, you want to lay the foundation for an industry that will ensure that no one—whether in the coming decades or in the 22nd century, depending on your level of optimism—will ever want for a life-saving organ again. To do that, you can't go at it by hand.

"You'll need a device that's able to create the same type of organ time and time again," Atala told me. "Just like it was machine-made."

One afternoon, I stopped by the desk of John Jackson, an associate professor at the institute. Jackson, 63, is an experimental hematologist by trade. He came to Wake Forest four years ago, and likened the move to the insti-

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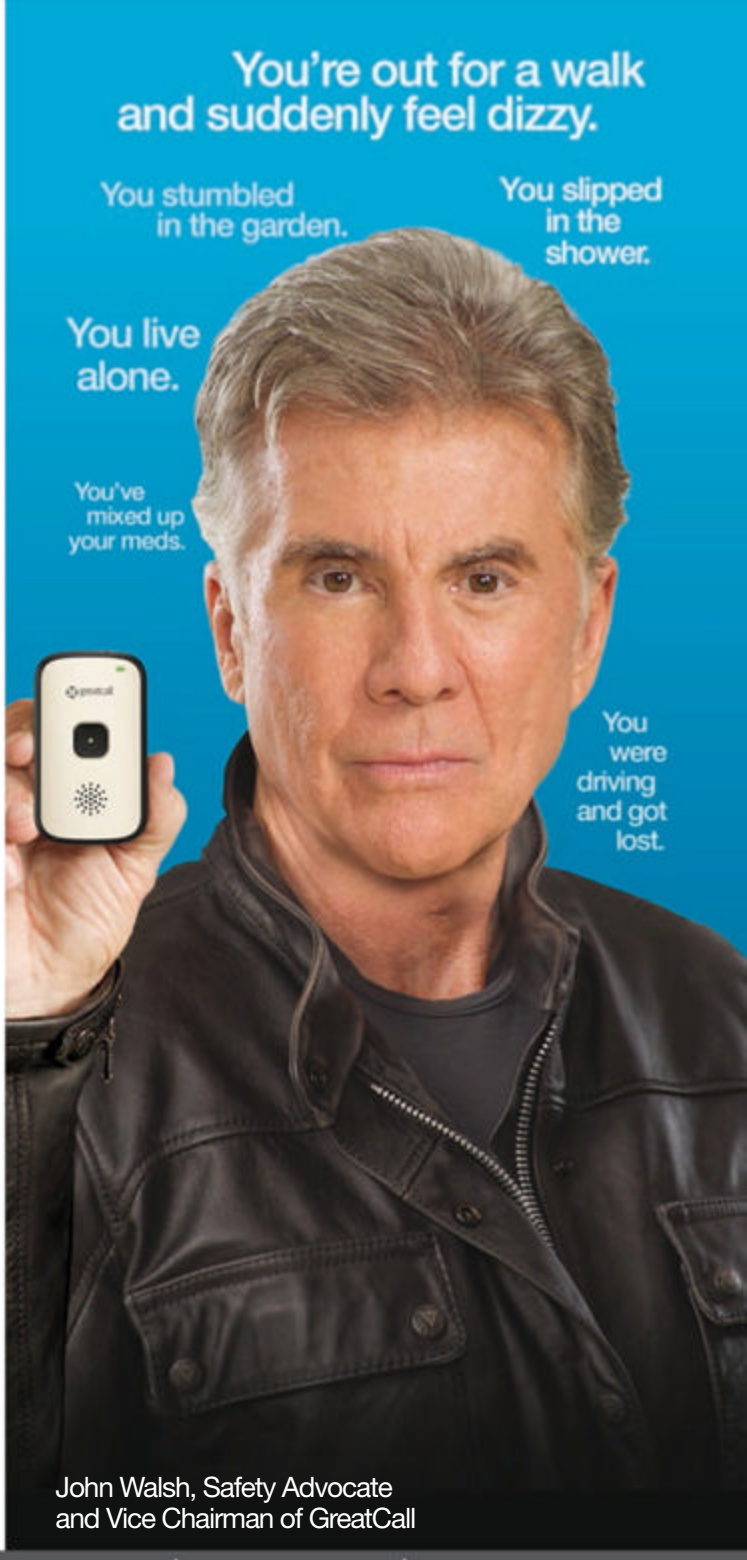
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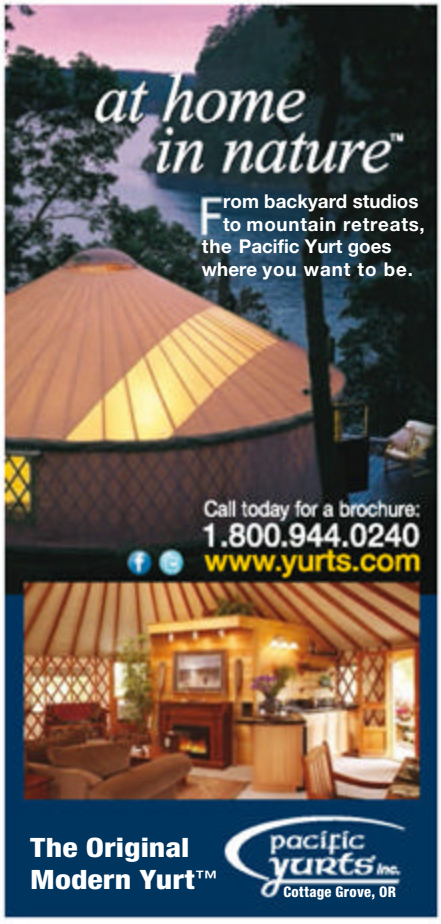
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Jackson oversees the development of a skin-cell printer, which is designed to print a range of living skin cells directly onto a patient. "Say you have an injury to your skin," Jackson suggested. "You'd scan that wound to get the exact size and shape of the defect, and you'd get a 3-D image of the defect. You could then print the cells"—which are grown in a hydrogel—"in the exact shape you need to fit the wound." Right now, the printer

"At the end of the day, I went into medicine to take care of patients. I love having that relationship with families and patients."

can lay down tissues at the top two layers of skin, deep enough to treat—and to heal—most burn wounds. Down the line, the lab hopes to print deeper beneath the skin's surface and to print more complicated layers of skin, including adipose tissue and deep-rooted hair follicles.

Jackson estimated clinical trials could start in the next five years, pending FDA approval. In the meantime, his team had been busy testing the skin printer on pigs. He unscrolled a large poster, which was divided into panels. In the first was a detailed photograph of a square wound, about four inches on one side, that technicians had cut on a pig's back. (The pigs had been put under general anesthesia.) That same day, the researchers had printed cells directly onto the wound, a process that took about 30 minutes. In the post-printing photographs, you could make out a discrepancy in color and texture: The area was grayer and duller than natural pig flesh. But there was little puckering, no raised or ridged scar tissue, and, in time, the gel more or less completely melded into the surrounding skin.

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The skin-cell printer is one of several active projects at the institute that receives funding from the U.S. Department of Defense, including tissue regeneration initiatives for facial and genital injuries, both of which have been endemic among American soldiers injured in recent wars. Last year, researchers led by Atala announced the successful implantation of vaginas engineered using the patients' own cells in four teenagers suffering from a rare reproductive disorder called Mayer-Rokitansky-Küster-Hauser syndrome. Wake Forest is also testing lab-grown and decellularized cadaver penises and anal sphincters on animals, with the hope of starting human trials in the next five years.

The Peripheral, the new novel by the futurist William Gibson, who coined the term "cyberspace" and foresaw most of the digital revolution, takes place at a time when humans are able to "fab"—essentially 3-D print—anything they need: drugs, computers, clothing. They are constrained only by their imagination. And yet hunched over Jackson's poster, I found myself thinking that even Gibson hadn't predicted this: living flesh, on demand.

I walked over to Atala's office. Sunlight splashed across the floor and a tall set of bookshelves, which displayed photos of Atala's two young sons and several copies of his textbook, *Principles of Regenerative Medicine*.

He'd been in the operating room all morning (he's also the medical school's chairman of urology) and did not expect to head back home until late in the evening, but he was cheery and burbling over with energy. I asked him if he ever considered giving up his practice and focusing solely on research.

He shook his head. "At the end of the day, I went into medicine to take care of patients," he said. "I love having that relationship with families and patients. But equally important, it keeps me in touch with what the need is. Because if I see that need firsthand, if I can put faces to the problem—well, I know I'll keep working on it, keep trying to figure out."









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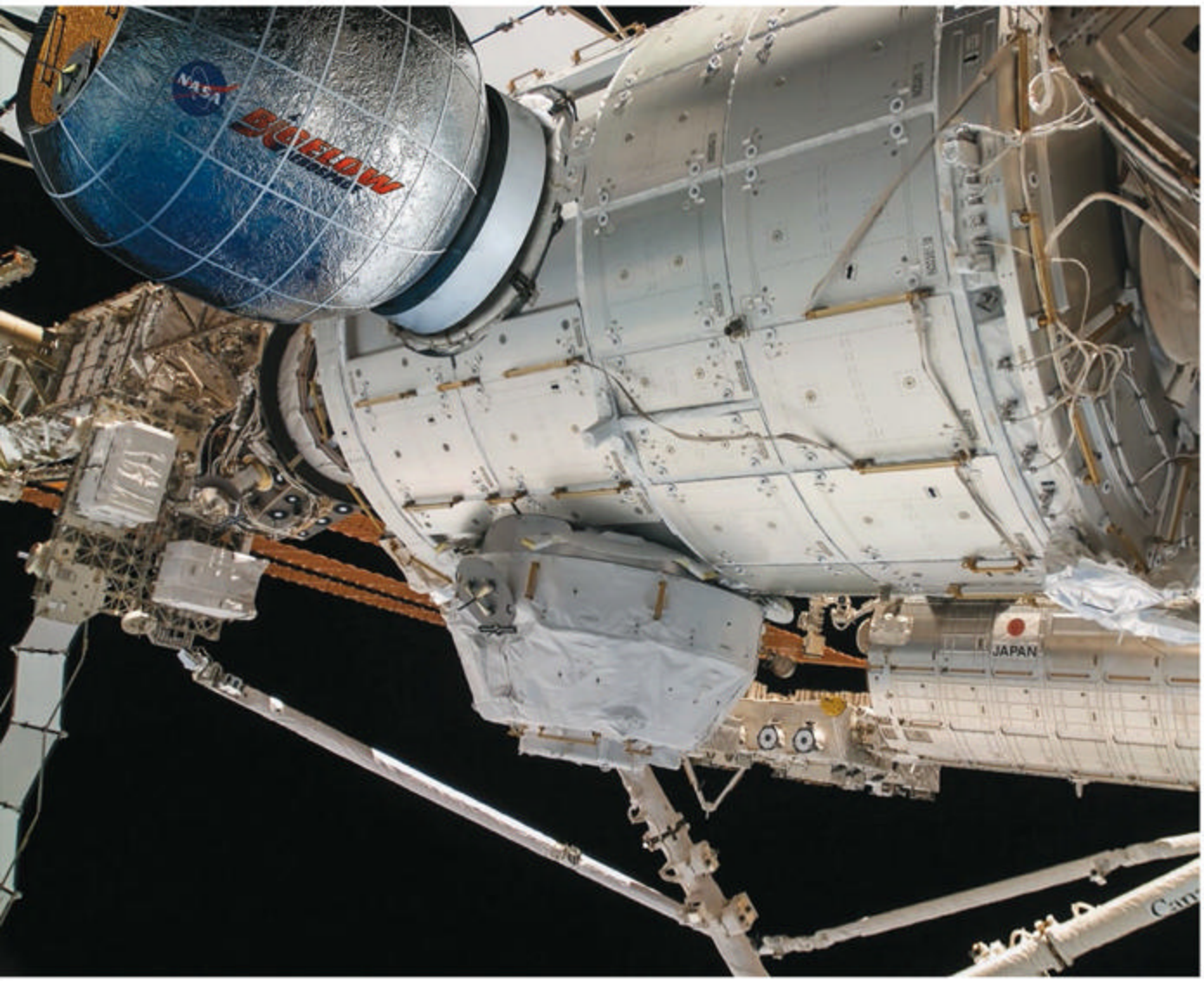
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ISS Blows a Bubble

Like the rest of us, astronauts could always use a little more breathing room—the trouble is lugging it into space. Now NASA thinks it has found a solution, in the form of a shiny new addition to the International Space Station: an inflatable den.

The Bigelow Expandable Activity Module (BEAM) is a tentlike structure that fits inside a rocket nose cone, then expands to 565 cubic feet, about the size of a minivan. After it berths with the space station, the BEAM will fill with pressurized breathable air, pushing the envelope out to form a rigid outer layer of a shock-absorbing, Kevlar-like weave. The habitat will debut in space later this year on the CRS-8 mission, under NASA's contract with Elon Musk's SpaceX company, and an astronaut will set foot inside an inflatable habitat for the very first time.

The manufacturer, Bigelow Aerospace, is already working on roomier lodgings, about 12,000 cubic feet, for long-term missions. These expandables will accommodate crews of up to six people, with space for research, storage, sleeping and living quarters.

Mike Gold, Bigelow's director of D.C. operations, believes that these systems could replace ISS after the program ends in 2024. Expandable modules could be docked together to form a "space complex" supporting future missions to the moon, Mars and beyond. Because the architecture of the structures is flexible, he says, "you don't have to keep reinventing the wheel." –VICKY GAN

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THE MOON SHOTS PROGRAM

MD ANDERSON'S BOLD PLAN TO CRUSH CANCER BY 2023

Imagine a future without America's most-feared disease. By current estimates, 40% of us will develop cancer in our lifetime; 80% will watch it ravage a relative or friend. This year, cancer will kill nearly 600,000 men, women and children in the U.S. And over the next decade it will take an estimated 100 million lives worldwide. But at The University of Texas MD Anderson Cancer Center, an unprecedented research initiative called the Moon Shots Program is imagining something far better:

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Getting there will be "the fight of the 21st century," acknowledges MD Anderson President Ronald A. DePinho, M.D., who announced the ten-year, $3 billion Moon Shots Program in 2012, on the 50th anniversary of President John F. Kennedy's proclamation that America would send a man to the moon. The goal: Slash cancer death rates. "Humanity urgently needs bold action to defeat cancer," DePinho says. "The Moon Shots Program signals our confidence that the path to curing cancer is in clearer sight than at any other time in history."

The Moon Shots Program is taking aim at cancer's deep complexities in new ways. Innovative research engines are under development to put personalized treatment options at doctors' fingertips—and draw on patients' experiences to bring new treatment possibilities to light. Multidisciplinary collaborations are teaming laboratory scientists, frontline oncologists, IT professionals and even lawmakers to translate what we know—and are learning—about cancer into real-world tactics (such as gene tests for breast- and ovarian-cancer survivors and a new Texas law limiting teenagers' use of tanning beds) that accelerate the prevention, detection and treatment of cancer. Immunotherapy agents are unleashing the power of the body's immune system to confront this disease, leading to the launch of the world's first "intent to cure" clinical trial for prostate cancer.

The project's inaugural focus is on eight cancers responsible for more than 50% of all cancer deaths: lung, prostate, melanoma, breast, ovarian and three types of leukemia. More will be added along the way. The Moon Shots Program is among the most formidable endeavors mounted to date by MD Anderson. It is an institution ranked as one of the top two hospitals in cancer care nationwide for 25 years by *U.S. News & World Report*'s Best Hospitals Survey and a research center at the forefront of exploration for breakthroughs in cancer prevention and treatment for nearly 75 years.

"Nothing on the magnitude of the Moon Shots Program has been attempted by a single academic medical institution," notes Frank McCormick, Ph.D., professor emeritus at the University of California, San Francisco Cancer Center and past president of the American Association for Cancer Research, who led a review panel that helped determine the project's first cancer targets. "Moon Shots takes MD Anderson's deep bench of multidisciplinary research and patient care resources and offers a collective vision on moving cancer research forward." Here's how the program's innovations are yielding results today—and moving us all closer to a world without cancer.

CANCER PREVENTION: TEEN BAN ON TANNING BEDS
For Texas teenagers, a trip to the tanning salon before the junior prom may be a thing of the past. In 2013, the state legislature banned the use of tanning beds by anyone under the age of 18. The new law was a response to an advocacy campaign that joined leaders from MD Anderson with those from other major health organizations.

THE MOON SHOTS PROGRAM'S ROLE: Provide data on links between indoor tanning and skin cancer. Use of tanning beds before age 18 boosts risk for melanoma, the deadliest skin cancer, by 85%. Tanning beds expose skin to a concentrated source of UV radiation, damaging DNA within skin cells. So far, 11 states have enacted similar laws and the momentum continues to build.

COLLABORATION: Ovarian Cancer's New Math

Ovarian cancer accounts for just 3% of all cancers in American women. But it's ferociously lethal, taking more than 14,000 lives annually. "It's a scary diagnosis," notes a schoolteacher and marathon runner who came to MD Anderson in Houston in 2013 with stage 3C ovarian cancer—an advanced form of the disease her own doctors initially mistook for gastrointestinal trouble.

Her treatment engaged the new



© Randy Faris/Corbis

Anderson Algorithm, an early success story to emerge from the Moon Shots Program. The algorithm, adopted as a standard protocol in 2013 by the center's 21 gynecologic cancer specialists, relies on independent assessments by two surgeons via a laparoscopic exam to determine which women with advanced high-grade serous ovarian cancer should have surgery right away—and which need chemotherapy first to reduce the size of the tumor prior to surgery.

In the past, many underwent major surgery immediately, even though it removed all visible traces of cancer from the abdominal cavity for just 20–30%. Now the success rate has risen to 88% at MD Anderson—an advance that can improve survival. A year after her procedure, the Texas teacher was cancer-free and back to running races. "The approach worked for me," she told reporters. "I hope it works for everyone." Anil Sood, M.D., professor and vice chair for Translational Research in the Department of Gynecologic Oncology & Reproductive Medicine at MD Anderson, expects women's survival times to improve as a result. "This is a much smarter, much more personalized approach that's allowing [us] to make a huge difference," he says. Other cancer centers are paying attention to the new approach. "It's been a huge change in the way we provide care. Every time we present the information from this algorithm, there is a tremendous amount of interest."

CANCER GENOMICS: Finding Hidden "Previvors"

One Moon Shot focuses on high-grade serious ovarian cancer (the most malignant form of the disease) and triple-negative breast cancer (a partic-

ularly aggressive form likely to spread and recur) patients and their families. People with either of these cancers are now offered genetic screening for mutations in the BRCA1 and BRCA2 genes, which elevate a person's risk for both cancers. A woman with a BRCA mutation has a 50–85% lifetime chance of having breast cancer and a 27–44% chance of getting ovarian cancer. If she has already been diagnosed with breast cancer, she has a 40–60% chance of getting cancer in the other breast.

If patients test positive, their sisters, daughters and other relatives may have the same inherited mutation. So finding mutations can help survivors sidestep new cancers and protect family members, too. "We encourage patients to communicate their results with other family members, offer our help in facilitating that communication and also offer them genetic screening," says Moon Shot flagship project leader Banu Arun, M.D., professor of breast medical oncology.

Now it's allowing more women to make lifesaving decisions. One hundred and fourteen of the first 1,644 cancer patients in the Moon Shots' REACH (Research, Education and Awareness of Cancer family History) program tested positive for BRCA mutations. Forty-five enrolled in an outreach program that identified at-risk relatives. Carriers—including cancer survivors and "previvors " (those with a genetic predisposition who do not have cancer)—are offered lifesaving options. Surgery and cancer-prevention medications can lower risk for future cancers, while stepped-up screenings may catch breast cancer earlier. Removal of the ovaries can reduce ovarian cancer risk by 95%, while taking oral contraceptives may lower odds by 50%, says Karen Lu, M.D., professor and chair of Gynecologic Oncology.

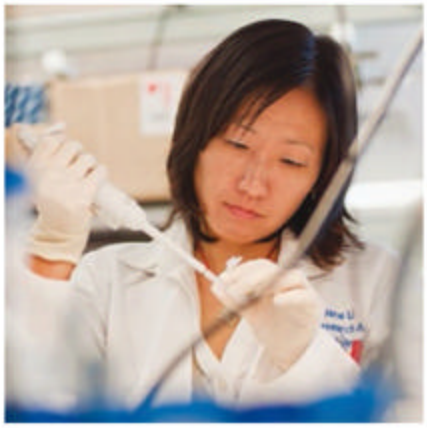
"If we catch more people before they're diagnosed or before a second unrelated breast cancer, and we can affect their families, then that is a true disease-free benefit," says Jennifer Litton, M.D., an associate professor of breast medical oncology.

Breast and ovarian cancer patients found to have the mutations are offered treatment in clinical trials of PARP inhibitors, drugs that target defects caused by BRCA mutations.

BIG DATA ANALYTICS: Training IBM's "Watson"

Since its 2011 victory on the TV show *Jeopardy*!, IBM's Watson computer has slimmed down by 90% (shrinking from the size of a master bedroom to three stacked pizza boxes) and become 24 times faster. But teaching Watson to think like an oncologist so the supercomputer could power the Moon Shots Program's new MD Anderson Oncology Expert Advisor™ (OEA™) system is no small undertaking.

Learning from MD Anderson's cancer specialists in weekly meetings, IBM engineers are deploying Watson's natural language processing and analytic skills to learn all about leukemia. Over 18 months, the world's smartest computer digested data on 10,000 leukemia patients as well as hundreds of thousands of pages of medical research. End result: the September 2014 debut of the OEA™ Leukemia solution, a first-of-its-kind cognitive clinical decision support system that offers 24/7 on-demand access to expert opinions for acute leukemia treatment and management, with at-your-fingertips scientific and



clinical evidence to help physicians make the best decisions in patient care. OEA™ system development is now expanding to the Lung Cancer Moon Shot. Ultimately, the OEA™ team hopes it will give doctors worldwide access to the best care options for individual cancer patients.

The OEA™ system works by suggesting "the most personalized appropriate evidence-based therapies out there," says Courtney DiNardo, M.D., an assistant professor of leukemia, whose background in biostatistics adds a new dimension to her OEA™ training as a subject matter expert (SME). "It's not just a Google search or an analysis of published research literature. We have those already. What this does is take information about your patient—their clinical story, the characteristics of their specific cancer, treatments they've had in the past, medications they take for other conditions—and synthesize it with available literature to suggest individualized treatment options."

OEA™ will never replace your doctor, DiNardo is quick to add. "We hear all the time that the future will be robots and computers, we won't need doctors at all. But the ultimate treatment decision rests in the hands of the physician, and patients. There's always a human dimension to patient care beyond the data. Personal preferences...logistical and financial concerns...all of these are in the realm of the patient-physician relationship. If there are two equivalent therapies and one is given daily as a pill, the other as an injection less frequently, the choice is up to the doctor and patient. OEA™ can't answer that question." It can't handle patient consent forms or contraceptive advice either, she adds.

It will give patients new hope. "One important aspect of the MD Anderson Oncology Expert Advisor™ is that it will not solely rely on established cancer care pathways to recommend appropriate treatment options," notes Lynda Chin, M.D., professor and chair of Genomic Medicine and scientific director of the Institute for Applied Cancer Science at MD Anderson, who is the visionary driver behind development of the OEA™ system. "The system was built with the understanding that what we know today will not be good enough for many patients. Therefore, OEA™ will automatically screen every patient for appropriate clinical trials, so participating in clinical trials will not be a last-resort option but an up-front option that physicians and patients can consider."

In a nutshell, the OEA™ system is a tool to augment, not to replace, physicians. We believe that a system like that will expand/spread MD Anderson's expertise far beyond Houston to the 14 million people around the world who get a cancer diagnosis each year, says Chin. "OEA™ can democratize expertise in cancer care, taking it to people who do not have access to the expertise today and are therefore at risk of not receiving the most effective care right now." In turn, the infrastructure and network built to



support the OEA™ system in democratization will facilitate aggregation of lessons learned by oncologists from all over the country and the world, which will lead to even better cancer care for all. "If we can begin to learn from more patients," Chin says, "research will be more effective, because conclusions from our studies will be more applicable to a larger population."

APOLLO: The "*N* of All"

Every research project involving human subjects has an *n*—the number of people in the study. Chin is enthusiastic about the potential and is enthusiastic about MD Anderson potential to create an "*n* of all" approach to research and care—that is, the ability to aggregate information from, and learn from, every patient treated at the center. The engine behind this is APOLLO (Adaptive Patient-Oriented and Longitudinal Learning and Optimization).

APOLLO creates an efficient system for longitudinal collection and aggregation of patients' high-quality tissue and blood samples for genomic and molecular analyses. The data are linked to complete a clinical medical record of the patients and centralized in the institution's big-data platform. Analytics can then draw upon such a treasure trove of patient big data to generate hypotheses for research and insights for care. The OEA™ system is an example of a cognitive analytic application that will draw from such big data.

"A central theme of the Moon Shots Program is to learn as much as we can from every single patient," says Andy Futreal, Ph.D., professor of genomic medicine and co-leader of the Moon Shots Program. He leads APOLLO. "We need to think longitudinally—how patients' conditions, treatments and tumors change over time—and be smarter about how we collect and use that information."

By seamlessly blending patient data with the latest research insights and best practices in clinical care, and analyzing it over time, APOLLO will help researchers improve patient care by understanding factors that determine treatment response, resistance, toxicity and survival. "We're building an engine to accelerate the translational process," Futreal says. "Every cancer research institution on the planet is struggling with this right now. Raising the quality of our information is going to benefit everyone."

IMMUNOTHERAPY: Unleashing the Body's Attack Dogs

The five-year survival rate for advanced melanoma, the deadliest of skin cancers, has hovered at a dismal 10–20%—until the recent discovery that the breakthrough drug ipilimumab (Yervoy) takes the brakes off the immune system so it can recognize and extinguish malignancies. The applications of this exciting new treatment extend to many other cancers, including several Moon Shot focuses.

"Immune checkpoint blockade treats the immune system, not the tumor, so there's a strong basis for expecting this approach to succeed across cancer types. Clinical trials at MD Anderson are exploring that possibility right now, and there will be more to come," says Jim Allison, Ph.D., MD Anderson's chair of Immunology and executive director of the immunotherapy platform.

Allison's basic science research on the biology of T cells—the attack dogs of the immune system—laid the foundation for the development of the drug. Ipilimumab works by blocking a molecule that normally keeps T cells on a short leash. The drug can silence melanoma for years in 22% of patients, Allison says. Immunotherapy is now a validated standard-of-care treatment for cancer patients and is an established modality, along with surgery, chemotherapy, radiation and targeted therapy. Now the Moon Shots Program is initiating crucial clinical trials in melanoma and breast, lung, colon and pancreatic cancers.

Early research using ipilimumab and a second immunotherapy agent, nivolumab, is yielding impressive responses for the majority of melanoma patients. DePinho says there's a "solid likelihood" that this therapy will reduce advanced melanoma mortality by 50% in the next ten years. •

PROTEOMICS: READING CANCER'S FINGERPRINTS

Genetic tests reveal what a cancer may do. In contrast, cancer proteomics measures actual proteins on the surface of and within tumor cells—giving researchers and doctors clues about cancer processes and about why a treatment succeeds or fails. One of the Moon Shots Program's most innovative research engines, the proteomics platform is deploying high-tech tests to help find ways to detect cancer earlier and to overcome treatment resistance.

ONE PROMISING APPLICATION:

Moon Shots researchers have launched a first-of-its-kind clinical trial for a particular treatment-resistant prostate cancer. They're combining two drugs—abiraterone and enzalutamide—to block the resistance pathways that arise in each drug alone. The goal is to decrease the levels of testosterone that drive the cancer. Christopher Logothetis, M.D., professor and chair of Genitourinary Medical Oncology at MD Anderson, calls it "the first intent-to-cure clinical trial for prostate cancer."